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REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1929–1930.*

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BY

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I am frequently asked the question: What is the general nature of the problems which are in progress at the Bartol Research Foundation? The answer is that we are pursuing investigations in the physical sciences, with particular emphasis on those having to do with fundamental or keynote processes in physics. Such a statement has a very clear cut significance to the specialist, but since its meaning is not so clear to the layman, it may be of interest to amplify it a little further; and to this end a sort of analogy will be helpful. It must frequently have seemed very remarkable to many of us that when we pick up the receiver of the automatic telephone in our office, and dial the appropriate number, we get that number almost immediately, in spite of the fact that the telephone service is at the call of several million people. Yet, we know very well that if we were to examine the process by which the apparently infinitely complicated business of telephoning is brought about, we should find that it is operated by the application of one or two fundamental principles in the organization of the procedure in such a way that if we have a clear idea of those principles, there will be no difficulty in understanding the possibility of my telephoning almost instantaneously to Mr. John Jones in Chicago. A very great

* Presented at the Stated Meeting held Wednesday, April 16, 1930.

number of wires, switches and cables may be involved in our getting connection. My act of telephoning to Mr. Jones may be a matter of very great *complexity*, but if I understand the principles of organization of the telephone service aright, it will not be one of great *perplexity*. And so, the secret of understanding any complicated organization is to seek out those fundamental activities of the organization which control its behaviour, and which permit of the great complexity of operation which is desired without the accompaniment of great perplexity as to how the whole thing takes place. And so, in endeavoring to understand the ways in which things happen in the physical universe, it must be the business of the physicist to seek out those keynote processes which, when he knows them, will enable him to understand the enormously complex processes going on in the universe itself. In the telephone service, it is to the ingenuity of man that we owe the fundamental processes of the activities which make the telephone a success, so that we can inquire as to their nature by going to the telephone switchboard and having somebody show us the process. In the realm of the physical world, however, it is the Grand Architect of the Universe who has designed the processes. We cannot go into the telephone exchange of the Universe and look at the mighty switches which control the behaviour of nature. We are often in the position of the telephone subscriber who sits in his office and who perchance, in some thoughtful mood, having come to meditate upon how the telephone works, has set himself to try various stunts with the instrument on his desk, and those on the desks of his friends, in an endeavor to deduce from any versatility of action he may find in them, some kind of mechanism which may exist in the operation of the appliances, and which would account for the service which he finds the telephone can render. Of course, in order to complete the analogy, we must allow our telephone subscriber the liberty of playing all sorts of pranks to test out his particular hypotheses. We must not object if occasionally he chooses to blow up one of the offices of the telephone building in order to see what effect that has upon the operation of the others; or he may do something to put his telephone out of commission altogether, and see how it affects his friends, and so forth.

The Directors of the grander telephone of the Universe do not mind these little playful activities on the part of mankind as our President would have minded corresponding activities on our part when he was chief engineer of the Telephone Company.

The layman is frequently interested in another aspect of research, namely, that which has to do with the question of its ultimate usefulness. I can well suppose that if you should enter a physical laboratory, approach an investigator who seems very intent upon some experiment which for the time being absorbs his whole effort, and if you should ask him why he was doing that experiment, probably the only honest answer he could give you was that he liked doing it. You must not run away with the idea, however, that because he likes doing it, therefore it cannot be of any use. Many years ago, at a time when I was plugging away hard about sixteen hours a day, a man who was not a physicist, by the way, and who was not particularly enamoured of hard work, irritably told me that he didn't consider that what I was doing was work at all. "Why not?" said I. I was a little peeved, because as a matter of fact, I thought that I was working rather hard. "Well," he said, "you like what you're doing"; from which I deduced that his definition of work was "That which was unpleasant." However, what are we to say to the layman who sees nothing but the utilitarian standpoint in science, and demands of all things that fundamental researches must be, ultimately, of value in what he understands as the utilitarian sense? To him I would talk thus: "On this earth a thousand years ago there existed all of the elements and all of the appliances wherewith to make a radio tube. It is perfectly conceivable that an army of monkeys playing with these various things in the jungles of Africa might some day or other accidentally put them together in such a way that they constituted a radio tube. By accident, they would some day do the various things which were necessary to make glass. By accident there would be a flame somewhere into which the glass would happen to fall. By accident some monkey would at the time be exhaling breath through a tube whose free end happened to fall into the molten glass, resulting in its being blown into the appropriate form, and so on. Once in an æon,

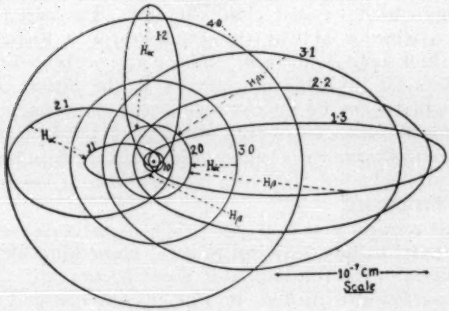
these monkeys would most assuredly produce a radio tube. In all probability, we should have to wait a very long time for that tube, longer even than the poor physicist, about fifteen years ago, used to have to wait for one of these tubes when he ordered them through the ordinary channels." The example that I have taken is a drastic one, yet it is truly illustrative of the importance of fundamental research. The process of hitting upon something accidentally is one which is not unknown in the world of science. When it does happen, it is very startling, and much publicity is given to it, so that one is apt to forget that most of the developments that take place nowadays in the utilitarian fields of knowledge, have come about by research after a more complete understanding of the fundamental processes in science, processes which to the layman would appear to have very little connection with the ultimate product in which he unconsciously uses them. Thus, if the monkeys to which I have referred, should accidentally construct a radio tube tomorrow, the phenomenon would receive far more publicity than would all the painstaking developments incidental to the production of that appliance by the Western Electric Company and the General Electric Company. Man is instinctively a gambler—he loves chances, and the things which happen for no reason always seem more unusual and alluring to him than the painstaking development of organized procedure. And so it is not always clear to the layman that there is very much connection between the abstruse things which he finds the physicist doing in the laboratory, and the practical things which he is doing. He sees before him the radio tube. What are the things which impress him most? I suppose the socket is the most eye-catching part of it, and indeed that has some elements of ingenuity about it, enough to warrant its giving a very good impression of the company which designed it. Then he sees those wires inside the bulb. They don't seem very complicated, and he naturally thinks that if anyone were to set about to develop a radio tube, the things which he ought to concentrate his attention upon are such things as just where to put those wires, and how thick they ought to be, and in particular, how to design that socket. He little knows that the things that have determined the design of that tube involve a knowl-

edge of the way in which the number of the electrons emitted by a wire varies with the temperature, of the way the electron emission varies with what is called the thermionic work function of the coating on the filament. He little knows the importance of the fact that for every one hundred thousand million molecules of air originally in that radio tube, the number which exist in the vacuum now in it is only about one or two. He little realizes how much an understanding of the molecular processes going on in a gas was necessary to produce the pump which created that vacuum. He uses the radio tube as a warrior of war times might use a torpedo, or a modern shell, seeing only the exterior and without knowledge of the detailed invisible mechanism in the inside. And so, while it will always be for the love of the chase itself that the physicist will pursue his search, he has every reason to believe that when full account is taken of his stewardship, he will not have to apologize on the basis of pure utilitarianism for the fruits of his labors.

I must remind you that, according to the views of the immediate past, at any rate, an atom is something like a little solar system. Its fundamental constituents are positively charged particles or protons and negatively charged particles or electrons. At its center is a heavy positively charged nucleus containing protons and electrons; and, around this nucleus revolve electrons in orbits as planets revolve around the sun. The heavier atoms have many protons and electrons in their nuclei, and many electrons describing orbits around them. One of the most common activities of the atom is that associated with the production of light; and, according to the theory of atomic structure invented by Niels Bohr, emission of light from an atom occurs in the following way. Occasionally, an electron which normally resided in, let us say, the orbit A, was hurled by some agent into an outer orbit. After remaining there for a time, it returned to its original orbit, or to some other one, and emitted radiation during the process, the wavelength or color of the radiation depending upon the orbit from which the electron fell, and the orbit to which it fell. According to the Bohr theory of atomic structure, only certain orbits are possible for the electron. These orbits are calculable from a rule given by Bohr, and Fig. 1 is a picture of the sup-

posed possible orbits for the atom hydrogen, which consists of a single proton for a nucleus with an electron revolving around it. These orbits are labelled according to the work which one would have to do to remove the electron, from the orbit, to infinity. To interpret this diagram properly, you must add together the numbers associated with each orbit. Those orbits which give the same total number correspond to the

FIG. 1.



same energy level. According to the Bohr theory, the innermost possible orbit is a circle corresponding to a perfectly definite amount of energy necessary to move the electron to infinity. The next nearest orbit to the center is represented by a pair of orbits, one a circle and the other an ellipse, but each having the same value for the energy necessary to move the electron from the orbit to infinity. Going still farther out we come to three possible orbits, a circle and two ellipses, each of them having again, the same energy necessary to remove the electron to infinity, and so on. In the more detailed refinements of the theory, the energy levels which I have spoken of as being the same, are really slightly different from each other, but different to such a slight extent that it is, for many purposes, convenient to regard them as the same in talking of their relationship to other energy levels which differ materially from them. In the atomic theories which have developed during the last three or four years, this picture of Bohr has been very

materially altered. The atom is spoken of in much more abstract terms than one which deals with planetary orbits and models of this kind. However, much of the language of the Bohr model remains, and we shall not be led materially astray in speaking, for our present purposes, in terms of it.

Now a situation of this kind immediately raises a number of questions concerning fundamental activities in the atom itself, such questions as these. Given a large number of atoms under bombardment by some external agency which disturbs their electrons, in what fraction of the total number of atoms will any particular orbit in this figure be occupied by an electron? Again considering an electron in any one of these orbits, how long will it stay there before it springs back to its original orbit near the nucleus, or to some other orbit inside its present one? If it does decide to leave its present orbit, what is the relative chance that it will dive into some orbit B, as compared with the chance that it will dive into some orbit A, and so forth?

To speak in rather more exact language, we may say that, according to the purely formal representation of the matter which preceded the modern wave mechanical picture of atomic processes, the atom could exist in any one of many energy states; and, when in any state other than that of lowest energy, there was a certain probability that in any element of time, dt, there would be a transition to one of the lower states. In terms of these various probabilities, it was possible to calculate the average time which must elapse for the number of atoms in any given excited state to become reduced to any given fraction of their original number ($1/e$ is the fraction taken, where e is the base of the Napierian system of logarithms). This time is the quantity customarily designated as the mean life of the excited state.

Since the intensity of any spectrum line originating in a certain state is determined at each instant by the number of atoms per c.c. in that state, the way in which the intensity of the spectrum line falls off with time is related in a calculable manner to the way in which the number of atoms in the state in question falls off, so that measurements of the rate of decay of intensity provide a means of arriving at the mean lives in the excited state from which the lines originate. Incidentally,

it may be remarked that the development of the details of the theory leads to the interesting conclusion that all spectrum lines originating in the same upper energy level should have the same mean life.[1]

EXPERIMENTS ON THE MEAN LIVES OF ATOMS.

Now it is in problems of the foregoing kind that Dr. L. R. Maxwell has been carrying on investigation at the laboratory. In particular, he has been interested in determining the mean life of an atom in an excited state. He is interested in knowing how long any one electron will remain in any one of its possible orbits if it is placed there, and how the length of the time de-

[1] For those familiar with the language of the subject, the following discussion will be of interest.

Let N be the number of atoms which, at any time t, have an electron in an excited state designated by the quantum numbers nk. Then, $A_{nk}^{n'k'}$ be the probability of transition from the state nk to state $n'k'$, the number of electrons which will leave nk and go to $n'k'$ in time dt is given by

$$-dN_{nk}^{n'k'} = A_{nk}^{n'k'} N dt.$$

Thus the total number of electrons which will leave the state nk per unit time, is

$$\frac{-dN}{dt} = \Sigma_{n'k'}\left(-\frac{dN_{nk}^{n'k'}}{dt}\right) = \Sigma_{n'k'} A_{nk}^{n'k'} N,$$

where the summation is to be extended over all the possible states to which the electron can jump. Therefore, the population N of the nk level at any time t is given by

$$N = N_0 e^{-[(\Sigma_{n'k'} A_{nk}^{n'k'})t]},$$

where N_0 is the number of atoms with an electron in the nk state at the time $t = 0$.

The energy emitted per unit time at time t by the jumping of electrons from state nk to $n'k'$ is $A_{nk}^{n'k'} h\nu_{nk}^{n'k'} N$, where $\nu_{nk}^{n'k'}$ is the frequency of the emitted light. Therefore, the intensity of the spectral line is given by the following, after replacing N by its value from the above equation,

$$I_{nk}^{n'k'} = A_{nk}^{n'k'} h\nu_{nk}^{n'k'} N_0 e^{-[(\Sigma_{n'k'} A_{nk}^{n'k'})t]}.$$

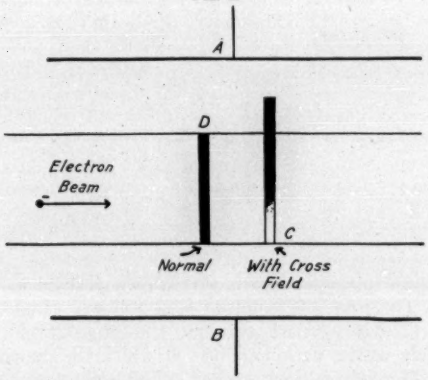
The average life τ of the excited state nk is given by

$$\tau = (\Sigma_{n'k'} A_{nk}^{n'k'})^{-1}.$$

We see from this equation that all of those lines caused by electrons jumping from the same level should give the same value for the mean life. This simply means that the life of an excited state can be measured by using any line which originates from that particular level. The intensity of a line, however, will depend upon the value of $A_{nk}^{n'k'}$ as shown by the equation for $I_{nk}^{n'k'}$.

pends upon the particular orbit in which it is placed. He is interested in knowing how the length of these times depends upon the particular kind of atom in which the orbit is to be found, and so on. At the time of my report last year, he had made certain progress towards the solution of this problem, and I must briefly recall the nature of the means used. He passed a beam of electrons through an evacuated tube containing mercury vapor. The electrons bombarded the mercury atoms and caused them to emit light, and this light could be analyzed by a spectroscope into a number of different wave-

FIG. 2.



lengths having the characteristics of the light emitted. As you know, by means of the spectroscope we are able to illuminate a vertical slit with the light, and cause it to appear in another part of the apparatus as a number of slits with distinct colors, separated from each other. The positions of these colored images depends upon the wave-length of the corresponding light. In Fig. 2 the electron beam is shown diagrammatically and in Dr. Maxwell's experiment it passes between two plates A and B, between which an electric field could be established. Let us suppose that we focus the light from a certain portion of this beam onto the slit of the spectroscope, the slit being perpendicular to the direction of the beam,

and let the two vertical lines *D* and *C* represent by their degree of blackness what we may expect to see, in two representative cases. If the atoms which are excited to emit light are uncharged, then we may expect to see in our spectroscope a line which has the same intensity at the top as at the bottom as in the case *D*. If, however, the act which excites the atom also removes another electron from it, the atom will start to move upwards immediately it is excited, and when it emits light, it will be, on the average, farther from the lower edge of the beam than it was when the excitation occurred. The net result of all of this will be that the lower portion of the slit will be robbed of its light, and the upper portion may even be caused to extend beyond the boundary of the beam itself as in *C*. If the life in the excited state is very short, there will be very little disturbance of the intensity by the field; but if the life in the state is long, the disturbance will be much greater; and, without going into detail, it will be sufficient to remark that by measuring the distribution of intensity over the vertical line *C*, it is possible to deduce the time which the atom remains in its excited state. In this deduction, many elements must be considered, and allowed for. These are described fully in Dr. Maxwell's publications [2] and I will not describe them now.

For the measurement of the distribution of density over the photographic image, an instrument known as the densitometer is used. The principle involved is as follows. Light from a lamp is caused to pass through the photographic image successively at the various points at which the density is required. The light is then allowed to fall upon a photoelectric cell which is connected with a suitable electric measuring device in which the displacement of a fine fibre becomes the ultimate measure of the intensity of the light falling upon the photoelectric cell. The fibre is in turn photographed on another plate, and its displacement from its normal position gives a measure of the light which has succeeded in getting through the photographic image of the original plate at the point under investigation. The mechanism holding the two

[2] "Spectra of Mercury above the Ionization Potential," *Phys. Rev.*, Vol. 32, pp. 715–720, 1928. "Determination of the Mean Life for the 4797A Spark Line of Doubly Ionized Mercury," *Phys. Rev.*, Vol. 32, pp. 721–726, 1928. "Mean Life for the Mercury Spectrum," *Phys. Rev.*, Vol. 34, pp. 199–206, 1929.

plates are coupled together in such a manner that they can be made to move together in any corresponding ratio, in a direction perpendicular to the displacement of the photographic image of the fiber. Thus, as the first plate containing the photographic image of the line is caused to move over a slit which allows the light to pass through it, the other plate moves in corresponding fashion, and records a curve whose ordinate at any point is a measure of the light allowed to pass through

FIG. 3.

the corresponding point of the original photographic image of the line. The difference between the reading on this curve at any point, and the corresponding reading in the absence of the primary plate gives, of course, the density of the photographic image on the primary plate at the point in question. Figure 3 is a photograph of the densitometer used in Dr. Maxwell's later experiments.

Now, in the first place, this method gives us a ready means of finding which of the spectrum lines are produced by atoms which have become charged in the process of excitation; and, as I will remind you, Dr. Maxwell had already shown last year, that the so-called spark lines of the electric discharge are charged in this manner, and he had also determined the mean lives for certain spectrum lines in mercury as indicated in Table I. This was a distinct step forward in showing by

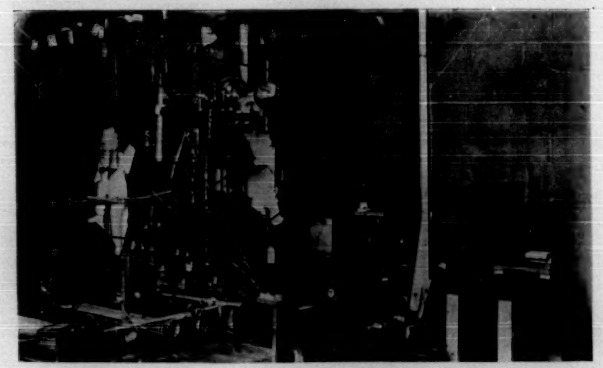
TABLE I.

The Mean Life for the Mercury Spark Spectrum.

Wave-Length of Line (Å).	Type of Ion Responsible for Line.	Mean Life (sec.).
3090	Hg^{++}	6×10^{-7}
3312	Hg^{++}	4×10^{-7}
4797	Hg^{++}	4×10^{-7}
2572	Hg^{+++}	8×10^{-7}
3114	Hg^{+++}	9×10^{-7}

direct experiment what we had already surmised from other considerations, that the time which an electron would remain in the excited state was of the order of one millionth of a second or less. It now became of interest to pursue the experiments in such a manner as to obtain data capable of being correlated with known theories of the atom in such a manner that they might form a test of the story which those theories

FIG. 4.



have to tell. For this purpose it is desirable to use a very simple atom. Hydrogen immediately suggests itself; but, if one removes an electron from a hydrogen atom there is nothing left but a proton, and a proton has no means of emitting light at all, so the simplest structure which is practically usable is one which, in its normal state, before the removal of one of its

electrons, has two electrons revolving in orbits around its nucleus. Such a structure is helium, so during the last year Dr. Maxwell has been working upon the mean lives in the excited states of helium. On account of the fact that the atom of helium is so much lighter than that of mercury, the effect of the electric field in pulling the charge sideways is much greater than with mercury; and, for this reason it is possible to measure mean lives of short duration. However, the mean lives in the case of helium are of such very short duration that this consideration alone would not have rendered it possible to measure them had it not been for certain alterations in technique, mainly, in the matter of the nature of the electron beam which I will not now take time to describe. Figure 4 represents Dr. Maxwell's apparatus, the tube in which the electron beam performs its ionization is shown at *A*.

FIG. 5.

B is a bulb for purifying the helium, and *C* is an electromagnet whose purpose was to produce a magnetic field parallel to the length of the electron beam. The function of this field was to hold the electrons in the beam and prevent their scattering by self repulsion.

Some of the spectrum lines excited by an electron discharge in a gas, do not show the shift under the influence of an electric field because they are produced by uncharged atoms. Measurement of the distribution of intensity across the line in the case of these atoms affords a measure of the strength of the electron beam at different points of its cross section, and a comparison with the density distribution of such a line with another which has come from a charged atom gives the effect of the motion of the charged atom. Figure 5 is an actual photograph showing a line due to an uncharged atom and one

due to a charged atom. Figure 6 is the densitometer record for the two lines showing in a more visual form the actual displacement produced by the electric field. The next picture,

FIG. 6.

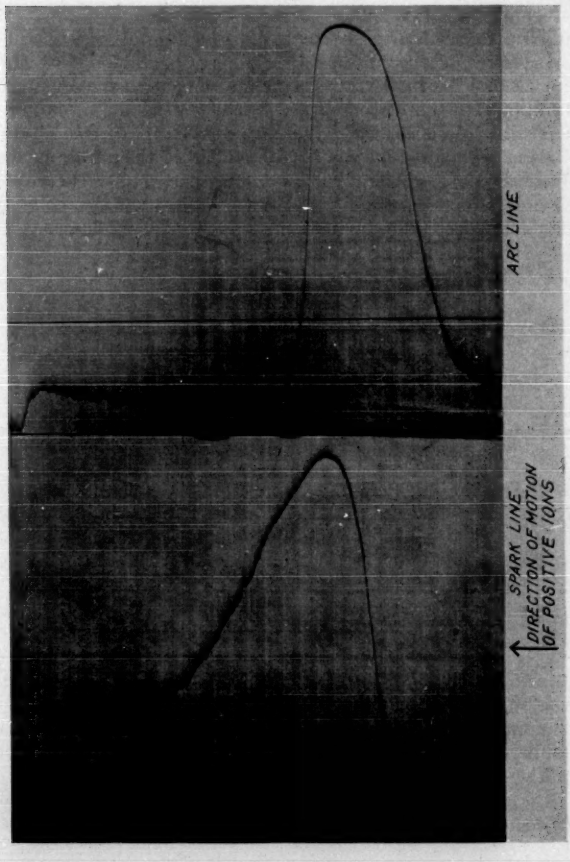


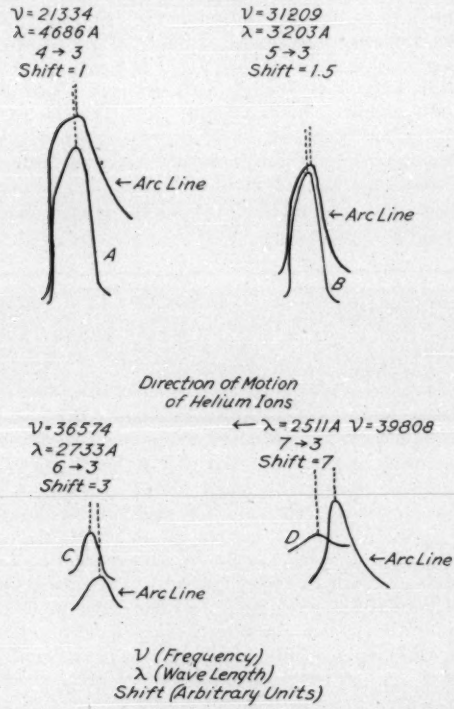
Fig. 7, is of fundamental interest. It contains the displacements of many spectrum lines in the spectrum of helium, the displaced lines being indicated by arrows. Unfortunately, it is impossible to represent satisfactorily in a photographic print, the distribution of density in these lines with that degree of exactness which would be necessary for satisfactory measurement, and which exists on the original plate from which the measurements were taken. The photograph is reproduced simply for the purpose of indicating the kind of spectrogram which one obtains in these cases. Now we know from spectroscopic considerations, how these lines have originated. That is to say, we know the energy levels in the atom between which they represent electron jumps. Dr. Maxwell has picked out a set of four lines which correspond to the electron jumps from different higher energy levels to a

FIG. 7.

single common lower energy level, the normal energy level for the helium atom, and he finds that the further the orbit is from the nucleus the greater the mean life of an electron in that orbit. The further the electron is from home the less anxious it is to go back. We can observe the story of this phenomenon by examining the displacement of the various lines found in the negative from which Fig. 7 is taken; and, for this purpose it is convenient to refer to the densitometer records, or rather to curves obtained from them, and showing the variation of density in the displaced line, and in an adjacent undisplaced line, plotted against distance measured parallel to the line. Such curves are shown in Fig. 8. *A*, *B*, *C*, *D* represent lines which have been produced by electron jumps from orbits of successively larger radii; and, it will be seen that the displacement of the maxima of intensity (indicated by the distances between dotted lines) increases with the frequency of the light,

and so with the remoteness of the initial orbit from the nucleus. Figure 9 shows a curve in which the abscissæ are the wave-lengths of the lines and the ordinance represent the displace-

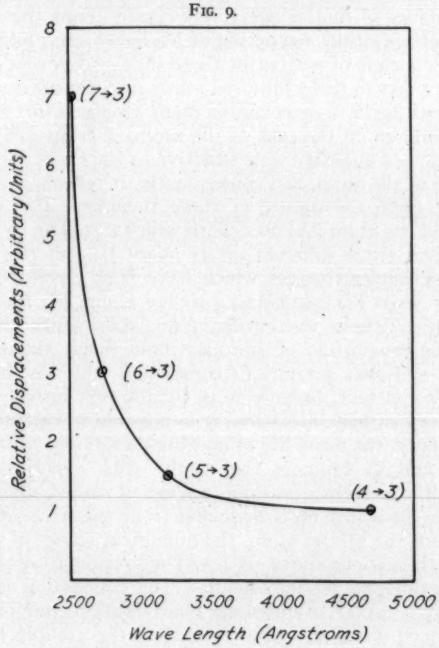
FIG. 8.



ments of the points of maximum intensity of the lines from their undisplaced positions in the absence of the electric field. While Dr. Maxwell wishes to make certain refinement in the

methods before calculating the actual final numerical values of the mean lives, the curve gives, at any rate qualitatively, the history of the phenomena and brings out the very important conclusion that the mean life increases with the remoteness of the orbit from the nucleus.

FIG. 9.



Another point which has already been partially established, and upon which further measurements are being taken, is that having to do with the verification of the theoretical conclusion referred to above, and concerned with the fact that all lines originating from the same upper energy level should have the same mean life.

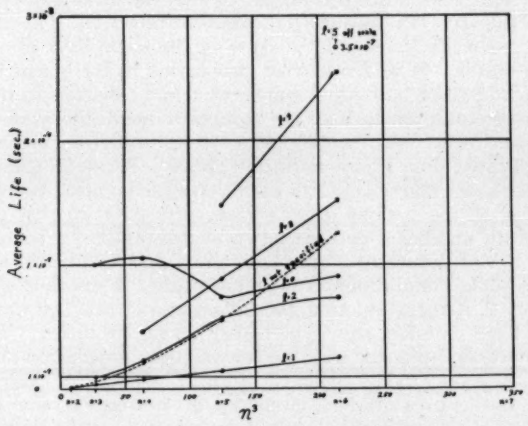
I was once asked of what use it is to know the duration of one of these mean lives. I can perhaps, give you an idea by taking the example of a measurement of the time it takes for a man to run a hundred yards. The time in itself is of very little interest, except that, taken in conjunction with other facts of a similar nature I might make use of it to determine many things of fundamental importance about the man, the length of his stride, the action of his heart, etc.; and if I had no other means of getting at these data, a knowledge of the time he takes to run a hundred yards might constitute a very important factor in determining many things of interest about him. And so, in the case of the atom, it turns out that the mean life is a quantity very sensitive to the exact form of our theories of the atom, and consequently, it reflects a very critical test upon the nature of those theories. The old Bohr theory of the atom had no definite story to tell as to what the mean lives of the different orbits might be, but the so-called wave mechanics theories which have been developed in the last few years have something to say about the matter, and they are so definite that, utilizing no experimental data other than the magnitude of the electronic mass, the electronic charge, and that mysterious constant h which is known as Planck's constant, because Max Planck first introduced it in the theory of heat radiation, it is possible to calculate, from pure theory, the mean life of an atom in any one of its excited states, and so compare the results with experiment. Dr. Maxwell is now engaged upon a series of rather laborious calculations in which he is deducing from the wave mechanics theory for the helium atom, the numerical values of the mean lives of the various states, with a view to comparing them with his experimental measurements. The calculation is complicated by a rather troublesome consideration, but one whose significance is happily proportional to the trouble it causes. I have remarked that, in general, in the Bohr theory, any one energy state can be realized in more than one way. The state denoted in Fig. 1 by a sum of the attached numbers equal to 3, for example, may be realized as a circular orbit, or as either of two elliptic orbits; but, the theoretical mean lives for each of these different types of orbit are quite different. It is convenient to use the conventional term *total quantum number*

for the sum of the numbers attached to an orbit. Now in an experiment in which the atoms are excited by the electron beam, and in which, let us say, a spectrum line under consideration is produced by a change from the state of total quantum number 3 to the state of total quantum number unity, we have to deal with three possibilities as regards the energy in the former state. Some of the atoms producing the light represents a jump from, let us say, the state 3.0; others from the state 2.1, and others from the state 1.2. The measured mean life is a sort of mixture of the mean lives of all of these states. If we knew what proportion of the atoms were in each of these individual states, we could calculate in terms of the separate mean lives the composite mean life measured by experiment. As a matter of fact, the situation is even more complicated than I have indicated above. A careful scrutiny of the theory shows that, for each value of the total quantum number n, the various states which correspond to that total quantum number n correspond to slightly different energies, and each of these states may be realized in a number of ways which make them different from each other in another sense. However, it turns out that the differences of this last named kind have no effect upon the transition probabilities. They do, however, influence what we may call the population of the states as more crudely depicted in Fig. 1. Thus, for example, if the state represented by, let us say, 4.1 in that Figure can be realized in p ways in this more refined analysis, while the state represented by 3.2 can be realized in q ways, it is customary to suppose that the number of atoms in the 4.1 state is p/q times the number in the 3.2 state. If we make use of this principle to determine the relative populations of the states as represented in Fig. 1, we have a means of calculating the quantity measured as the average mean life corresponding to any value of the total quantum number n. Following the principles laid down by Sugiura,[3] Dr. Maxwell has calculated the mean lives for various states in ionized helium. The results are represented in Fig. 10. The cube of the total quantum number n is plotted as abscissa, and the various full line curves correspond to the various ways in which that number n is made up out of its two component numbers r and l.

[3] *Journal de Physique*, Vol. 8, p. 113, 1927.

The dotted curve represents the average mean life corresponding to any value of n plotted against n after calculation according to the foregoing principles. It will be seen that, in accordance with Dr. Maxwell's experimental results, the mean life increases with n, in other words, with the distance of the orbit from the nucleus

FIG. 10.



So far, in view of the very short duration of the mean lives for ionized helium, the measurements which Dr. Maxwell has made for that gas can hardly be taken as representative of more than an approximation to the mean lives, sufficient to show, in the case of any two states, which one has the greater mean life. With the more refined method of attack which he is now planning, however, he hopes to obtain quantitative data to afford an actual comparison of the numerical values of the theoretical and experimentally measured mean lives.

Theoretical Investigation on Mean Lives.—I must remark that while the wave mechanics does not think of the atom in terms of planetary orbits, it does have in the more abstract language of its mathematical formulation, a place for what on the Bohr theory were the energy states corresponding to

different orbits, and it is a convenience of language to speak of these orbits even though they do not exist.

The matter of testing the agreement between theory and experiment in the case of these mean lives is of particular significance because, although I have spoken of the theoretical calculations of the mean lives as a very definite business, it is really not as certain as I have implied. In fact, the modern theories of atomic structure have not crystallized themselves into perfect consistencies as regards the different stories which they tell. In the formal development which the wave mechanics theory has taken, the theory leads to a set of light producing vibrations taking place in the vicinity of the atom with the frequencies agreeing with experiment, but unfortunately, these vibrations would, according to the simple form of the theory, go on forever. It is customary to make a sort of break in the logical continuity of the theory at this point, and suppose that the radiation energy is really not emitted in the manner of continuous vibrations at all, but in the form of discreet units or quanta, in accordance with ideas already outlined, each quantum being of amount equal to the frequency associated with the vibration multiplied by the mysterious constant h of Planck. The relative probabilities of the transitions corresponding to the various spectrum lines are adjusted so that, on the average, the intensities of the light radiated in the different frequencies [4] are the same as would be given by the wave mechanics theory, with its undying radiations propagated without change forever. On this basis of calculation, the quantity known as the mean life in the older theory becomes calculated in terms of the data of the wave mechanics theory, in spite of the fact that in that theory itself, the mean life has strictly, no logical place at all, at least in the form in which the theory is usually developed.

Now you see, this part of the theory is in a rather messy state. I am having some difficulty in making it clear to you, and I will not accept complete responsibility for the fact that I may not have made it clear, because the clearer I make it, the more you ought to be dissatisfied with it. One has a feeling that there is something there, but that the story ought not

[4] With the understanding that the gas is kept in a steady state by constant replenishment of the quantum states which disappear on account of radiation.

to be told in exactly that way. It is true that the results following from this rather disreputable break in the logical continuity of the theory have provided it with some important successes as regards the ultimate comparison with experiments. However, one wishes that he could arrive at the final journey's end of the story by a route which did not involve such questionable procedures on the way. Now, as a matter of fact, the wave mechanics story does possess the power to tell the ultimate story of those phenomena concerned with the intensities of spectral lines in which the so-called mean life plays a part, but the situation as regards the story is rather peculiar. If one demands of the wave mechanics the exact story of any particular phenomenon, the position of the wave mechanics is rather like this. It says, "I will give you this story, but you'll have to take the story of everything else that goes along with it at the same time, and the work that you will have to do to extract from me the story that you want, will not be limited by the work for that story, but you'll have to work hard enough to make me give you all the information which I have about the whole matter. I will not tell you a single chapter of the book. I will only tell you the whole story, and the price will be the price of the whole book. You may, if you like, go to those little places around the corner, and buy pirated editions of the individual chapters, with very little effort, but you will find a lot of things about them which will not satisfy you. You will find that the type of the different chapters does not fit well together, and sometimes you will find a gap between one chapter and the next, or the chapters may even run into each other in such a way as to produce complete lack of harmony between them." Well, in spite of these difficulties, Dr. A. Bramley and Dr. A. Mitchell have become interested in the theoretical aspects of the question of the mean lives, and have devised a process by which they have softened the heart of wave mechanics a little, and gotten him to tell a more exact story of this particular region in which they are interested than was told before, without the expense of, as it were, buying the whole book. It would be very difficult in a short space to indicate the exact lines along which Drs. Bramley and Mitchell have attained this end. I can only say this much about it. If, considering an atom as a nucleus and an electron, one re-

gards the nucleus as a fixed origin of coördinates, and discusses the story in these terms, then he arrives at that situation to which I referred in which the vibrations predicted are vibrations which really go on for all time. If, however, one seeks to tell the story of the wave mechanics in a manner which pins neither the nucleus nor the electron down to a fixed point in space, which is the origin of the coördinates of our system of calculation, then the theory assumes a wider generality, and one which permits in a very natural way a situation in which the vibrations to which one is led, do die down with the time. As far as the general theory is concerned, they might die down at any rate you liked to assign, and the particular case where they do not die down at all, is simply one possibility out of the whole range of infinite possibilities where dying down does actually occur. In other words, the simple theory which neglects the possible motions of the nucleus is one which corresponds to a very highly improbable state, and a state which is very unsatisfactory as regards nature. Those who are familiar with the developments of modern theories in wave mechanics will recall that Dirac has invented a wave mechanical theory in which damping of the light vibrations is provided for. The attempt of Drs. Bramley and Mitchell is along quite different lines, and one of its objects is to secure a mathematical picture of the phenomena which follows more closely our intuitive pictures of the past decade than does the theory of Dirac. I make no apology for mixing up the description of Dr. Maxwell's researches with those of Drs. Bramley and Mitchell, because one of the most satisfactory situations which can arise, is one in which the work of different investigators gravitates spontaneously toward a common end, a situation in which the work of the different people is not limited to the specific problems which form the main avenues of their activities, but in which there is also a spontaneous coöperation in the matter of the different problems themselves.

ON THE ORIGIN OF CERTAIN COMET TAIL SPECTRAL BANDS.

Before leaving the question concerned with measurements of the mean lives of atoms, I must return to another aspect of the problem under investigation by Dr. Maxwell. This represents a sort of side issue. As I have already remarked,

the fact that the electric field which is perpendicular to the electron beam in Dr. Maxwell's experiment causes a redistribution of density in certain of the lines of the spectrum,

FIG. 11.

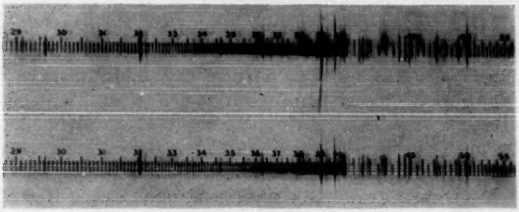
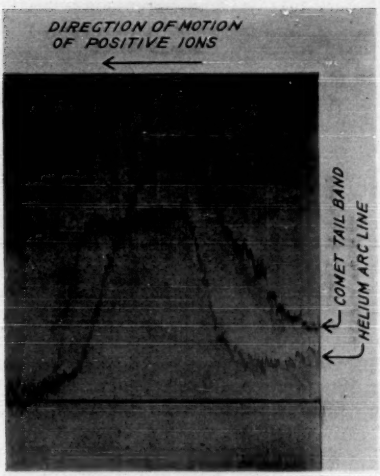


FIG. 12.



gives us evidence that those lines come from atoms which are positively charged. Now, in the spectrum of comets' tails there are certain bands whose origin has been a matter of some

discussion, and the question has arisen as to whether these bands are produced by neutral atoms, or by positively charged atoms. Dr. Maxwell has been able to produce these lines in the spectrum of helium contaminated with carbon monoxide. He has subjected them to the test of application of transverse electric fields, and Fig. 11 gives the results. The upper spectrum represents the effects of the electric field in comparison with the lower spectrum which is taken without an electric field. Careful scrutiny of the original, at any rate, shows that certain of the bands of the upper spectrum have a distinct displacement upwards indicating that the lines are produced by charged molecules or atoms. Fig. 12 shows the densitometer record of the same phenomenon for a single band, and exhibits rather more clearly the nature of the displacement produced. Table II gives the wave-length measurements of the bands investigated in the experiments, and the corresponding wave-length of the known comet tail bands, showing that they indeed represent the same lines. In order to understand the significance of this table, the explanation

TABLE II.

Wave Number of Band Head (Observed).	Wave Number of Band Head (Calculated).
21214	21207
21314	21333
21895	21896
22001	22021
23402	23390
23520	23515
24882	24870
24997	24995
26333	26322
26450	26447
27754	27746
27873	27871

following is necessary. The theory of the origin of these bands has been discussed by Birge,[5] who, from the known constants of the positively charged CO molecule has calculated the wave numbers (reciprocal of wave-length) of the origins[6] of the

[5] "Molecular Spectra in Gases," R. T. Birge, Bulletin No. 57 of the National Research Council.

[6] There is a slight difference between the significance of band "origin" and band "head" which however, is negligible for the matters under discussion here.

bands which would be expected from such a molecule. These numbers are recorded in the second column of Table II. They serve to identify from the whole mass of comet tail bands those which may be expected as produced by positively charged CO if such bands are present. The first column of the table gives the wave numbers for the heads of the bands which Dr. Maxwell found affected by the electric field in his experiments. It is to be observed that all of the bands that he finds affected by the electric field are included in those predicted by Birge.

It is a significant fact that the secret of producing these bands in the laboratory rests upon a proper adjustment of the relative pressures of helium and carbon monoxide. The carbon monoxide bands may be seen at helium pressures so low that the helium lines themselves do not appear at all. As the helium pressure is increased a stage is reached at which both the comet tail bands and the helium lines appear. As the pressure is further increased, the comet tail bands disappear and only the helium lines are left. They have entirely disappeared at a helium pressure of 3×10^{-3} mm. of mercury.

A further matter evolving from these experiments, but one having no particular connection with the comet tail bands, is of interest. Dr. Maxwell's spectrogram showed two broad lines having wave-lengths 2883*A* and 2896*A*. These lines, which are really closed up bands, are well known as belonging to what is called the "first negative group of Deslandres." A characteristic feature of this group is that its members are supposed to be produced by positively charged molecules. On the other hand, Dr. Maxwell's spectrogram shows no displacement for them as a result of the action of the cross electric field. We must, therefore, conclude either that the assumption that they are due to positively charged molecules is erroneous, or that the mean life in the excited state of the molecule is so short as to be unobservable in the experiments.

EXPERIMENT ON SENSITIZED FLUORESCENCE.

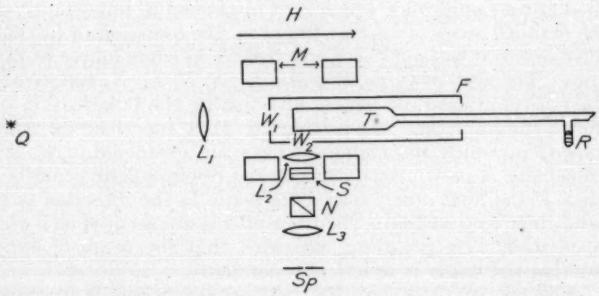
The Bohr theory, according to which the atom was a little planetary system, called, in certain cases, for a peculiar kind of memory in the atom. Now I am well aware that one does not usually speak of memory in the atom. And yet some of

the phenomena exhibited by the atom are controlled by what has happened to it in the past, in spite of the fact that the Bohr picture of the atom itself seems to contain no very obvious evidences of its past history. If an atom is subjected to radiation of a frequency which it itself is capable of emitting when excited, then it will become excited. It will in fact, absorb the incident light and re-emit it. Moreover, if the original light is polarized, that is to say, if the direction of the vibrations are all parallel to a single line in the wave front of the wave, then the light emitted by the atom in any direction lying in a plane perpendicular to the direction of vibration will also be polarized so as to vibrate in that same direction. According to the old classical theory of optics, there was, of course, no particular mystery in this. In so far as we had thought of any mechanism at all, the picture was one of a positive and a negative charge which were caused to oscillate backwards and forwards along the line of the electric field of the original light wave, with the result that they emitted light in which the vibrations were also parallel to this line. However, according to the Bohr theory, the production of polarization in the emitted light was rather surprising, because we were constrained to believe that the primary function of the incident light was to throw an electron from some orbit of the atom to an outer orbit, and our understanding of the situation was such that the light which was re-emitted when the electron fell back to its original orbit, might be re-emitted long after the original light had ceased to strike the atom, and after the electron had perhaps traversed the orbit many millions of times, so that there seemed no obvious reason for finding polarization in the resonance radiation (as it was called), which was emitted. Bohr was able to set up certain rules for predicting phenomena of this kind, but they were always of an artificial nature, and not much of an aid to understanding the phenomena. These rules suggested even more drastic possibilities as regards the memory of the atom. If we take a mixture of cadmium vapor and mercury vapor, and illuminate it with light from a mercury arc, then, as we know, very strong fluorescence radiation is produced in the mercury by a certain spectrum line known to spectroscopists as the line 2537, since that number denotes the number of one hundred millionths of

a centimeter in the length of the wave. Now there are certain lines in the cadmium spectrum which could well be excited by this 2537 line as far as its energy content is concerned; but, it is a well established principle that resonance radiation is not excited unless the wave-length of the incident light is exactly equal to that of the resonance radiation to be produced. However, the 2537 line can excite a mercury atom, and that mercury atom, when excited, and before it has emitted the radiation, may collide with a cadmium atom. Under these conditions, it is perfectly proper for the cadmium atom to utilize the energy which it has received from the mercury radiation, to excite the cadmium atom, and so give it the power of emitting radiation. Now the mercury atom remembers the direction of polarization of light in the original beam from the mercury arc, and the question arises, will it hand on that memory of the situation to the cadmium atom which it excites, so that when that cadmium atom emits light, the light also will be polarized in the same sense as was the original light which excited the mercury atom. Those familiar with the technical phraseology of the subject will prefer to replace my easy-going phrase 'memory of the atom' by 'a conservation of angular momentum' as between the original light and the excited mercury atom on the one hand, and the excited cadmium atom and the light subsequently emitted by the cadmium atom on the other hand. But the word 'memory' is a vague thing anyhow, and in the wideness of its vagueness there is a place for this more concrete idea of the conservation of angular momentum. The wave mechanics would have a story to tell as regards this phenomenon, but the story has not yet been worked out. However, here is a definite experimental phenomenon which would appear to have a sufficiently close relationship to the way in which things happen in the atom to provide a very drastic test of any theory which had in it the power of telling the story one way or the other. For this reason, Dr. A. C. G. Mitchell has been investigating the question, and Fig. 13 shows a diagram of his apparatus. It is necessary to have a suitable vapor pressure for the mercury and for the cadmium. If the pressure of the mercury vapor is too little, the amount of fluorescence radiation is too small for the experiment. If the pressure is too great, the secondary

...ation produced by the action of the primary light upon ...ms forms only a small fraction of the light emitted from the tube, since this secondary radiation on its way out, excites other atoms to resonance, and the light emitted by them excites still other atoms and so on. Under these conditions, while each encounter of a light quantum with an atom results in a secondary radiation whose polarization is related to that of the light quantum, the directions of the polarization of the various contributions to the light emerging from the tube become completely mixed up, so that the emergent light can-

FIG. 13.



not be expected to show any strong feature of polarization at all. The cadmium pressure has to be great enough to insure that the mercury atoms will produce enough collisions with cadmium atoms to result in a measurable amount of cadmium light; but, the pressure of the cadmium must not be too great, as otherwise it would prevent one observing the polarization of the cadmium light, which might be produced. The test that the pressure is high enough in the case of both the mercury and the cadmium, is that the cadmium lines are produced. Dr. Mitchell has endeavored to work with a minimum pressure of mercury and cadmium necessary to produce the cadmium line. The adjustment of the mercury vapor pressure is made by means of the tube *R*, Fig. 13, which contains a little liquid mercury. It so happens that if this tube is kept at room temperature, the desired conditions can be secured.

The pressure of the cadmium is controlled by having a little cadmium in the tube T, and surrounding the tube by a furnace whose temperature controls the density of the cadmium vapor during its distillation. With nothing but mercury vapor and cadmium present, the distillation of the cadmium out of the tube would be too rapid; and, consequently, a small amount of helium was admitted into the tube, and this had the effect of cutting down very greatly the rate of distillation of the cadmium. M represents an electromagnet which produced a magnetic field in a direction parallel to the original beam of light. While this magnetic field is very important for the practical realization of the experiment, and while it has a theoretical significance which is of fundamental importance in the detailed story of all that happens, the omission of further reference to it will not cause any trouble in what I have to say now. The system Q, L_1, W_1, W_2, L_2, S, N, L_3, S_p represents the optical system concerned with testing the polarization of the cadmium light. S_p is the slit of a spectroscope (not shown) in which the cadmium lines are examined. No arrangement is shown for polarizing the original light beam because if the final observations are made in the direction perpendicular to that beam, the same effects are secured as if the beam itself were polarized, provided that the beam of light entering the vapor is practically parallel.

The net result of Dr. Mitchell's observations is to show that if the radiation from the cadmium vapor is polarized at all, it is polarized to an extent less than 5 per cent. The significance of this statement may be gauged from the fact that the resonance radiation from the mercury itself is polarized to the extent of about 80 per cent. Of course, there are one or two elements of uncertainty as to the ultimate significance of this result. It is conceivable that the polarization which might normally exist in the cadmium light is destroyed by the cadmium atoms suffering collisions with mercury atoms, with each other, and with the helium, before they have a chance to emit the light resulting from their excitation. It must be remembered, however, that at the same time that he photographed the cadmium line, Dr. Mitchell also photographed the lines from the resonance radiation of the mercury. The result was that the emergent mercury light was found to be polarized

to the extent of 20 per cent. Since a consideration of the probable mechanisms of loss of polarization in mercury and in cadmium suggest a greater reason for loss in the former case, the survival of 20 per cent. of the polarization in the case of mercury is taken as good evidence that if any appreciable polarization had been produced in the cadmium, enough of it would have survived the ultimate emergence of light from the tube to have made itself evident in the observations.

AN INVESTIGATION OF THE POSSIBILITY OF DISSOCIATION OF MOLECULAR HYDROGEN BY POSITIVE IONS.[1]

It is a well known fact that atoms may have some of their electrons detached from them by bombarding them with other electrons to which a sufficiently high velocity has been imparted. The energy of an electron when in one of the normal orbits of an atom is less than when it is removed to infinity by a definite amount characteristic of the orbit which it occupies; and, it is known that if the bombarding electron possesses an amount of kinetic energy equal to this amount, it is able under suitable conditions of impact, to hand the whole of that energy to the electron in the atom and cause its escape therefrom. Now two atoms of hydrogen when combined to form a molecule have less energy than when widely separated, by an amount equal to that which the electronic charge would acquire in falling through a potential difference of 4.3 volts, and it might be supposed that an electron having a velocity corresponding to this fall of potential would be able to dissociate the molecule into its two atoms; but, experiment has shown that such is not the case. The bombarding electron has to have a velocity as great as that corresponding to a fall through a potential of 11.4 volts before it can cause dissociation, in any appreciable amount at any rate. It is probable that the situation is crudely analogous to that encountered in rolling a ball up a hill which is perfectly level at the top for an infinite distance. It is in general possible to give the ball a velocity sufficient to carry it to the top of the hill and it will then travel on to infinity. If, however, between this hill and the point from which the ball is thrown there is a higher hill, it

[1] Published in full under title "Behaviour of Positive Ions in Hydrogen," A. C. G. Mitchell, JOUR. OF FRANK. INST., v, 210, pp. 269–286, 1930.

will be necessary to throw the ball with a velocity great enough to enable it to reach to the top of this one before it will have a chance to get to the top of the other one and proceed to infinity. It is no consolation to it to know that the territory at an infinite distance is low enough to be reached with the velocity it has if it cannot surmount the high hill to be encountered on the way.

Now we might expect that if positive ions were endowed with sufficient velocity they would, on bombarding hydrogen molecules, cause them to split into atoms. However, in view of the fact that positive ions are thousands of times heavier than electrons, it would not be safe to expect that the energy which they would have to acquire in order to cause dissociation would be the same as that necessary in the case of electrons. It might be that the quantity which had to be the same in the two cases was the velocity rather than the energy. Without discussing the various possibilities in greater detail, it will suffice to remark that the question of a possible dissociation of molecular hydrogen by positive ions is one of very great interest in relation to the mechanism of the binding of the atoms in the molecule, and Dr. Mitchell has been carrying out certain experiments designed to secure information on the matter. It may be mentioned at the outset that no dissociation of the hydrogen by direct impact with the positive ions was observed within the range of velocities tested, and the results of the experiments have received an added importance from the fact that, while they were in progress, there appeared a publication on the same subject by two other observers [8] who claimed to have found such dissociation, and in surprisingly large amount; for using the data available in the publication, Dr. Mitchell has been able to show that the apparent results of these observers would correspond to the dissociation of about 10 molecules for each positive ion participating in the bombardment, whereas, in all analogous phenomena with electrons, the probability of dissociation is so small that only one molecule becomes dissociated for a large number of electrons participating in the bombardment. It may be mentioned that most of the disturbing influences incidental to an investigation of this kind act in the direction of

[8] A. Leipunsky and A. Schlechter, *Zs. f. Phys.*, v. 59, p. 857, 1930.

producing dissociation on their own account, so that considerable care is necessary in the design of the apparatus, and in the elimination of these disturbing influences to the end of being certain that dissociation which appears to have arisen from bombardment by the positive ions really does owe its origin to that cause.

The general principle employed to detect the production of atomic hydrogen depends upon the fact that if produced in a vessel immersed in liquid air, the atomic hydrogen will collect upon the cold walls of the vessel and so cause a diminution in the pressure of the gas in the vessel.

FIG. 14.

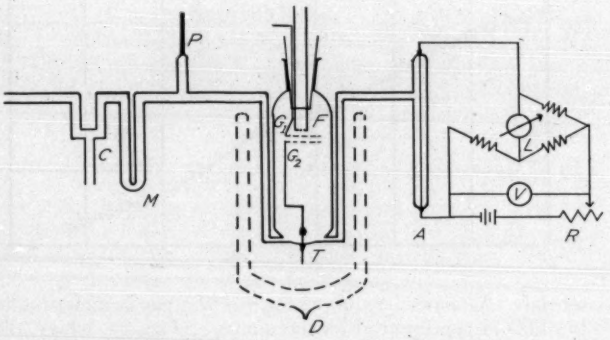
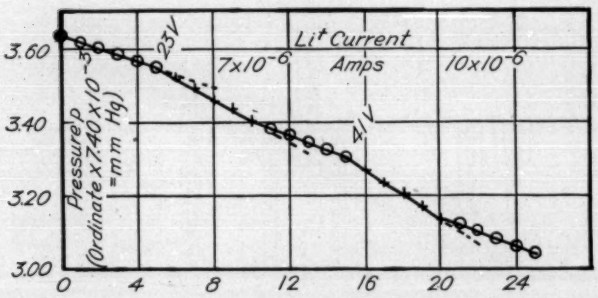


Figure 14 represents a picture of the apparatus used. The dotted lines represent a vessel containing liquid air, in which is immersed the tube containing the fundamental elements of the apparatus. These are as follows: first, an electrically heated filament F which was coated with spodumene ($LiAl(SiO_3)$), to give Lithium ions, or Pollucite (H_2O, Cs_2O, $2Al_2O_3 \cdot 9SiO_2$) to give Cæsium ions. G_1 is a wire gauze grid which could be set at a potential negative with respect to F, so as to result in an acceleration of the positive ions to the desired velocity. G_2 is another grid which was absent except in certain experiments of a subsidiary nature. C is a mercury cut-off, leading to a pumping system. M is a liquid air trap, P is a palladium

tube which permits hydrogen to pass through it when heated, and which serves to facilitate the entry of hydrogen into the apparatus. A is a Pirani gauge which, as will be recalled, measures the pressure of the gas surrounding it by the cooling effect of that gas upon an electrically heated wire. The apparatus to the right of A represents the electrical instruments associated with the gauge.

As soon as the filament F is lighted, atomic hydrogen starts to be formed, as is well known, by ordinary temperature dissociation, even though the grid and filament are at the same

FIG. 15.



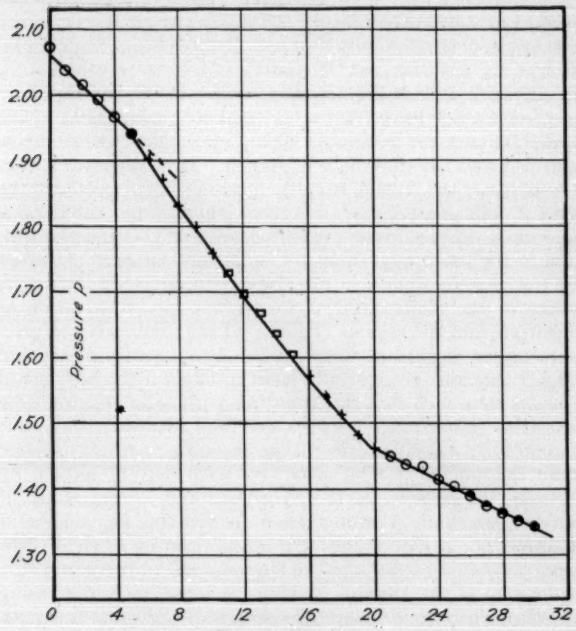
potential. As a result, the pressure of the gas commences to fall. This is represented in the curve of Fig. 15, where the ordinates give pressures and the abscissæ times. The six points indicated with circles at the extreme left of the curve represent this stage. As soon as a potential difference is applied between grid and filament, so as to accelerate the positive ions, the curve changes to that indicated by the five crosses to the right of the above mentioned circles, thus indicating an increase in the rate of diminution of pressure. On removing the potential difference, the curve changes back to the state indicated by the original set of circles, and on applying the potential again, it changes to the curve characterized by the dots, and so on in consistent manner.

It may be remarked that, even though the phenomenon should be interpreted without question as a dissociation of

molecular hydrogen by positive ions, it turns out that the number of molecules dissociated per positive ion is, at most, only one twentieth of the least value recorded from the experiments of Leipunsky and Schechter. However, Dr. Mitchell wished to make certain tests to establish with greater certainty the origin of the diminution of pressure following the acceleration of the positive ions. A spurious effect to be watched for in all work of this kind is dissociation of the hydrogen by electrons which have been produced by bombardment of the metal parts of the apparatus with positive ions; for, we know the electrons can dissociate hydrogen. It is conceivable that the positive ions coming from the filament might bombard the grid *F*, and produce there electrons which would travel back and cause dissociation in the region between grid and filament, and in the much larger region behind the filament. In order to test this possibility, a metal guard was placed across the plane of the filament so as to prevent any penetration of electrons into the regions behind. If the diminution of pressure under discussion were caused by electrons, we should expect that this guard would have no effect if the pressure of the gas were such that the mean free path of an electron were less than the distance between grid and filament, whereas it should have a decided effect if the mean free path were larger than this amount. The mean free path may be altered by altering the pressure of the hydrogen; and, consequently, if we plot the diminution in pressure per minute per ampere of positive ion current against the initial pressure of the hydrogen, we should expect that, in the presence of the guard, the ordinates would show a sudden decrease with decreasing pressure when the pressure was such that the mean free path of an electron became comparable with the distance between plate and grid, and should fall off with increasing rapidity as the pressure was lowered still further. In the apparatus under discussion, the mean free path became equal to the distance between plate and grid at a pressure of about 0.05 mm. However, in plotting the apparent dissociation against the pressure for pressures below this amount, the curve showed no abnormal decrease with diminution of pressure, but simply a more or less linear decrease such as would be expected if the electrons played no part in the phenomenon. As a further

test of this point, the apparatus was subjected to a magnetic field perpendicular to the axis of the tube. This field would

FIG. 16.



Experiment with C_s Ions

○ No Voltage on; no Magnetic Field on.
\+ 45 Volts on; no Magnetic Field on.
□ 45 Volts on; Magnetic Field 350 Gauss
◓ No Voltage on; Magnetic Field 350 Gauss
To convert pressures to mm Hg multiply by 8.45×10^{-3}

bend into cycloidol paths any electrons emitted from the grid, and a calculation shows that, with the magnetic field used, the electrons would not be able to approach the filament close

enough to acquire the energy necessary to dissociate a hydrogen molecule. Hence, if the observed diminution of pressure were due to electrons, it should be stopped by the application of the magnetic field. The field had no observable effect, however. The results of this test are shown in Fig. 16. The six circles at the left of the curve represent points obtained before the potential was applied to the grid. The five crosses to the right of these points represent the effect of applying the potential. The following five points marked with squares represent points taken with the magnetic field in addition. It will be seen that the magnetic field had no observable effect.

So far then, the evidence would appear to support the view that the apparent dissociation was brought about by the impact of rapidly moving positive ions with the hydrogen molecules. However, this conclusion is rendered very doubtful by the further evidence now to be given.

After the completion of the foregoing experiments, the grid G_2, Fig. 14, was inserted. If this grid was kept at the same potential as G_1, the positive ions which were accelerated to G_1 could pass through G_2 down the whole length of the tube. By putting G_2 at the same potential as the filament, or at a potential more positive, however, the velocity gained by the ions between F and G_1 could be destroyed between G_1 and G_2, so that the ions would fail to penetrate into the region of the tube below G_2, and carry with them any velocity which could enable them to produce dissociation there. If therefore, the apparent dissociation observed is real, and is caused by rapidly moving positive ions, it should be altered considerably in amount by changing the grid G_2 from the potential of G_1 to that of F. On the other hand, it was found that the potential of G_2 had very little effect upon the apparent dissociation observed. This seems to suggest that any effect which the positive ions may have in contributing to the phenomenon is not one involving their velocity. Further evidence to this effect is given by Table III, which, in the fourth column, gives the pressure diminution per minute per ampere of positive ion current, per unit of pressure of the gas, and in the fifth column, the potential difference between the filament and the grid G_1. If the quantities in column 4 resulted from the velocity of the ions, we should expect them to depend very markedly upon the

TABLE III.

Effect of Voltage.

A. Li Ions.

Rate $\times 10^5$ (mm./min.).	Current $\times 10^8$ Amps.	Pressure H_2 mm. Hg.	Average Rate $\times 10^{-2}$ $\left(\text{mm./min.} \times \frac{1}{\text{amp.}} \times \frac{1}{p}\right)$.	Volts.
11.1	15	0.0177	4.19	160
13.5	16	0.015	5.60	80
8.7	12	0.013		
9.3	10	0.024	3.87	41
9.3	23	0.026	5.12	7

B. Cs Ions.

Rate $\times 10^5$ (mm./min.).	Current $\times 10^8$ Amps.	Pressure H_2 mm. Hg.	Average Rate $\times 10^{-2}$ $\left(\text{mm./min.} \times \frac{1}{\text{amp.}} \times \frac{1}{p}\right)$.	Volts.
9.03	28	0.026		
9.75	28	0.026	1.37	320
9.86	26	0.0245		
12.0	30	0.0255		
11.5	30	0.020	1.75	240
11.3	21	0.033		
9.6	21	0.030	1.58	160
4.9	12	0.021		
2.8	12	0.019	1.59	40
2.18	6	0.029	1.25	20

values of the voltages given in column 5, instead of being independent of the voltage as shown. As already remarked, the *existence* of a potential difference between F and G_1 does promote the diminution in pressure referred to; but, the foregoing evidence supports the view that it is in bringing the ions off the filament that it performs its function rather than in giving them subsequently, the velocity which they acquire. The phenomena can be accounted for if we assume, as Dr. Mitchell suggests, that the positive ions form, with the hydrogen, a hydride, which condenses upon the walls of the liquid air cooled vessel. Such an assumption would account for all of the observed facts, and, in particular, for the most significant fact that while the rate of diminution of pressure per

ampere of positive ion current does depend upon the *existence* of a potential difference between F and G_1, it does not depend upon its amount.

THE REFLECTION OF ATOMIC HYDROGEN FROM CRYSTALS.

One of the subjects which has excited the greatest interest in atomic physics, during recent years, is that having to do with the reflection of electrons from crystals. It is a fact that electrons appear to be reflected as waves would be reflected, rather than as particles might be expected to be reflected, that originally gave rise to the entirely new viewpoint towards things atomic comprised in the so-called wave mechanics theory. In my report last year, I cited experiments which Dr. T. H. Johnson had been carrying out in the laboratory upon the reflection, not of electrons, but of atoms from crystals, in order to ascertain how far the phenomena which had revealed themselves in the case of the simple electrons would turn out to be characteristic of the more complex structure associated with the atom. The field of investigation stands in line with a series of developments which started as long ago as the time of Newton. The question of whether an atom is a wave or a small particle is in itself a new one; for the particle idea of the atom is one which has controlled our thoughts in the science of chemistry from the time that Dalton first proposed the law of multiple proportions, not to mention the speculations of the ancient Greeks on the atomic constitution of matter, and much research is being done at the present time to determine the diameters of the atoms, their masses, and other properties which we associate with the concept of a corpuscle. It is only within the last two or three years that it was suspected that atoms might also have properties which we usually associate with a beam of wave radiation. The dual aspect of light, however, has been hovering over us for over two hundred years. Today, the situation is much the same, with atoms and electrons as it has been in the past with light. Historically, the development in the case of light was somewhat reversed from what it has been with the other two wavicles (as these entities have sometimes been called), for although light was at first regarded as corpuscular owing to the ease with which shadows could be produced, the demands of

the beautiful phenomena of optical interference forced the train of scientific thought to the undulatory hypothesis; so that for more than one hundred years it was considered a settled question that light was a wave motion. It is only within the last two decades that its corpuscular character has been causing much worry, for it is only the relatively recent experiments in photoelectricity, etc., which really demand a return to a consideration of the possibility that light be regarded as a shower of corpuscles. Electrons and atoms on the other hand, were first introduced to us as corpuscles, and it is only within the last three years that the experiments of Dr. Johnson, and some other experiments carried on independently in Germany by Stern, have shown that the atoms are to be regarded as partaking of wave as well as corpuscular characteristics.

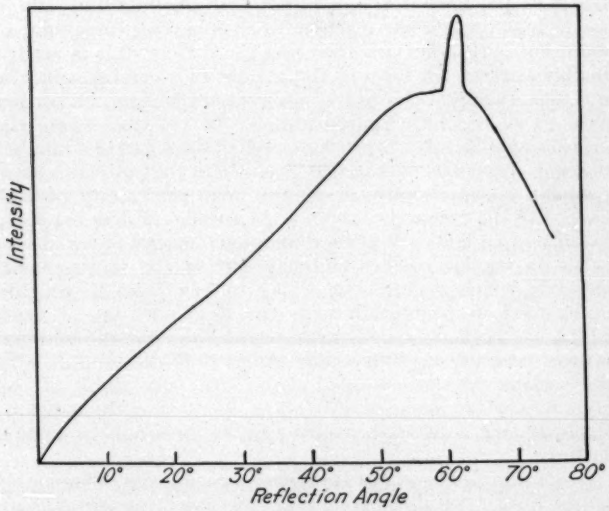
The philosophical question of how anything can be both a wave and a corpuscle is one which must be passed over rather lightly here, although it is one which has caused a good deal of consternation in the minds of many. It is probable that the apparent paradox is not as serious as appears at first sight, and that, in the case of both light, and electrons and atoms, we have to think of a wave which guides the particle in its motion, and of the particle itself as the actual entity which participates in the phenomena which make the light or the electrons and atoms evident in our experiments. Let us not pause to discuss, in detail, the philosophic aspects of this matter, but let us proceed to consider the classical basis of our conviction that light was to be regarded as an undulatory phenomenon. Perhaps the most representative of the experiments for illustration is that in which a beam of light is reflected from a surface upon which has been ruled many fine lines, evenly spaced. If the incident light is white the reflected light will consist of a regularly reflected beam of white light and on each side of it, in the directions perpendicular to the ruled lines, a series of beams appearing in the colors of the rainbow. The appearance of these colored beams is difficult to explain if we regard the light as a shower of corpuscles, but their explanation is simple if we assume that it is a wave motion with a wave-length of the same order of magnitude as the spacing between the lines which have been ruled upon the

surface. In fact, the experiment provides a means of comparing the wave-length of the light with this spacing, and it shows that we must have about ten thousand lines to the inch if the colored beams are to be separated, by an appreciable angle, from the regularly reflected beam. The lengths of the waves associated with electrons and atoms are much shorter than the wave-lengths associated with light. They are comparable with wave-lengths of X-rays; and, a grating which is to function properly in relation to them must be ruled not with ten thousand lines to the inch, but with one hundred million to the inch. Such fine machine work is beyond the ability of man, but nature has provided just the surface that is needed in this work in the form of the surface of a crystal, which is not to be thought of simply as a set of parallel lines, but rather as a set of regularly spaced atoms. In the case where the grating, as it is called, is not composed of lines, but of a number of regularly spaced dots in two dimensions, the pattern is more complicated but equally as definite as in the case of parallel lines. In the case where there are a number of dots regularly arranged in a lattice in three dimensions instead of two, there is also a regular pattern characteristic of the arrangement, and one which operates according to principles thoroughly understood in connection with the large amount of work which has been done in X-rays, where the three-dimensional lattices used are crystals whose atoms play the fundamental role of the regularly spaced dots. We may think of the crystal as acting in one of three ways—either as a three dimensional grating, a two-dimensional grating, or simply as a plane surface.

Now Dr. Johnson has been investigating the reflection of atoms from crystal surfaces, with the object of ascertaining how far the wave phenomena characteristic of electrons would reveal themselves also in the atoms. Atoms of hydrogen were chosen for the experiments; for, while these atoms are not the simplest ones to use from the experimental standpoint, they are the simplest from the theoretical standpoint, so that it is worth while to put up with a certain amount of experimental difficulty for the sake of securing results which may have the maximum of interpretable outcome in their significance in the newer theory. In my report last year, I described how

Dr. Johnson had shown that the possibility as regards a three-dimensional grating was ruled out by his experiments, and there remained the possibility of the crystal acting as a two-dimensional grating, or simply as a plane surface. In either of these cases, we should expect a beam of atoms reflected at an angle of reflection equal to the angle of incidence of the beam upon the surface. Dr. Johnson obtained such reflection,

FIG. 17.

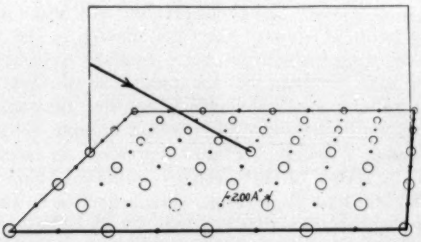


but as you will recall, it was mixed up with a large amount of reflection which was of an entirely different character, and of a diffused nature. I recall to you Fig. 17, from my last year's report. It shows a little peak in the intensity of the reflected atoms at the angle of reflection which was equal to the angle of incidence, in this case 60°, but it shows also, at other angles, a very appreciable number of atoms which did not obey the simple laws. Now, in seeking for the other reflected beams

which would correspond to the influence of the crystal as a surface grating, the diffracted beams as they are called, this extra diffuse radiation is a nuisance, and at the time of my last report, owing to its perturbing effect, Dr. Johnson was unable to conclude whether the diffracted beams were there or not. During the last year, he has found that lithium fluoride has the property of producing a very much purer specular reflection than rock salt. In fact, instead of having a relatively small amount of the beam reflected in the specular direction, he finds that, with lithium fluoride, about 90 per cent. of the beam is so reflected. Furthermore, and still more important from the point of view of the experiments, is the fact that even those atoms which are not specularly reflected are for the most part retained by the crystal until they combine together to form molecules which are not detected by the apparatus, and therefore fail to cause trouble by obscuring the phenomenon sought. Plate I represents an actual photograph of the record of the specularly reflected beam obtained from a lithium fluoride crystal. The reflection in the case of lithium fluoride is such that any reality which there may be as regards the existence of diffracted beams as distinct from merely reflected beams cannot be masked by diffuse reflection as was the case with rock salt. Only by the actual smallness of the intensity of the diffracted beam can they fail to make their appearance in the experiments. I must recall to you, that, in Dr. Johnson's experiment, the atomic hydrogen is detected by its influence in turning molybdenum oxide blue when it falls upon it, and the intensity of a beam of the gas striking any portion of the molybdenum oxide covered plate may be estimated by the degree of darkening as measured, subsequently, with a densitometer. It would be desirable, if possible, to work with a beam of atoms of a uniform velocity, since the atoms of different velocities are equivalent to waves of different lengths, and waves of different lengths have their diffracted beams in different directions. While Dr. Johnson is developing a scheme for working with beams of homogeneous velocity, the experiments which I have to describe at the moment were performed with a beam of atoms which had the ordinary distribution of velocity characteristic of its temperature. Now with such a beam, while the phenomena of diffrac-

tion are not as simple as they are with a beam of uniform velocity, they are such that it is possible to calculate the nature of the diffraction to be expected. Instead of having sharp spots as would be the case with beams of uniform velocity one would find, on the recording plate, a distribution of intensity with a maximum occurring at the place where there would be a sharp spot if all the atoms had a velocity equal to the most probable velocity of the atoms.

FIG. 18.



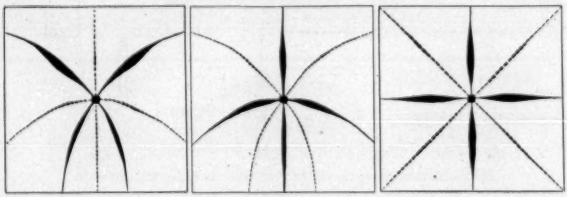
The arrangement of the atoms on the surface of an LiF crystal with respect to a beam incident in the 100 azimuth.

Figure 18 may be taken as representing, diagrammatically, the surface of a crystal of lithium fluoride. The circles and dots represent, respectively, the two types of ions. Let us consider three ways in which we may direct a beam of atoms at this surface. The first is represented in Fig. 18 where the plane of incidence of the beam is perpendicular and parallel, respectively, to the two sets of lines containing dissimilar atoms. The second is where the plane of incidence is at 45° to the former plane and is thus perpendicular and parallel to lines running through similar atoms. The third is where the beam of atoms is incident perpendicularly to the surface, in which case it is, of course, necessary to make it pass through a hole in the detecting plate in order to realize the experiment.

The question of whether the atoms in the lines perpendicular to the plane of incidence are similar or dissimilar really plays no part in determining the general form of the diffraction pattern obtained, although it does play a part in determining

the intensity of the pattern. As regards the general form of the complete pattern, Cases 1 and 2 are substantially the same, but they differ in respect to the relative intensities of the various parts. Thus the branches of the diffraction pattern which, in the customary terminology of the subject, would be classified as first order bands when referred to the rows of similar ions, become second order bands when referred to the rows of alternately dissimilar ions. Figure 19 represents by the full lines the first order bands referred to the rows of similar ions to be expected in each of the three cases, and by the dotted lines the second order bands. Plate II, *a*, *b*, and *c*, are photographic reproductions of the diffraction patterns actually obtained, but slightly retouched to make the half

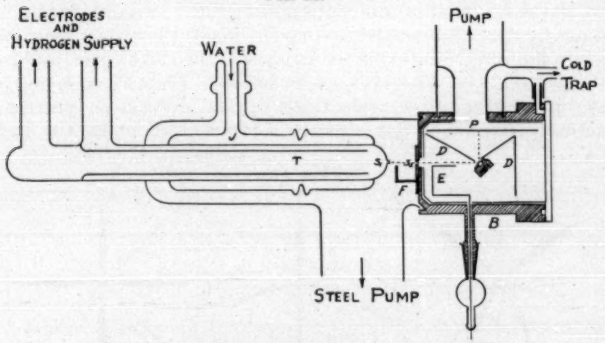
FIG. 19.



tone print look like the original. The experimental technique is thus far undeveloped to the extent that it is still difficult to obtain intense patterns unobscured by a diffuse background, but the essential features of the expected patterns can be seen. It is anticipated that, in the near future, all of the first order beams shown by the full lines of Fig. 19 will be obtained with sufficient intensity for quantitative intensity measurements, and, in addition, the indications are that it will be possible to photograph a large part of the second order pattern shown by the dotted lines of that figure. The wave mechanics theory enables us to calculate the length of the waves associated with an atom as a function of the velocity of the atom; and, from the wave-length, and the known atomic dimensions associated with the crystal we can calculate the exact size and shape of the diffracted pattern. The positions of the calculated maxima of intensity corresponding to the most probable wave-

length for the temperature distribution of velocity in the atoms agree with the most dense portions of the diffraction patterns in most cases. The intensity of the parabolic branches in Plate II, *b*, indicates that about one tenth as many atoms enter one of these bands in the first order as enter the specular beam.

FIG. 20.



Apparatus for studying the reflection of hydrogen atoms from crystals.

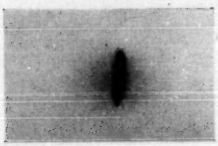
The apparatus used in these experiments is represented in Fig. 20. It represents no features fundamentally different from the apparatus which was described last year, and I need do no more than call your attention to the fact that the atomic hydrogen is produced in the tube T, and passes as a beam through the slits S_1 and S_2 on to the crystal at the center of the box B, from which it is reflected to the glass plate P coated with molybdenum oxide. The remainder of the apparatus has been described in its essentials before, and a detailed account of it will be found in Dr. Johnson's paper.[9]

CERTAIN INTERESTING PHENOMENA OF A SUBSIDIARY NATURE. THE EFFECT OF THE TEMPERATURE OF THE CRYSTAL ON ITS POWER TO REFLECT ATOMS.

When plane waves are reflected from a surface which is irregular to the order of a wave-length, the reflection consists

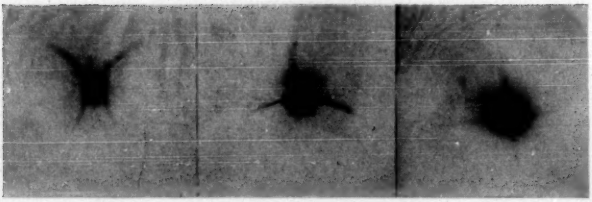
[9] "The Reflection of Hydrogen Atoms from Lithium Fluoride," JOUR. FRANK. INST., Vol. 210, pp. 135–152, 1930.

Plate I.



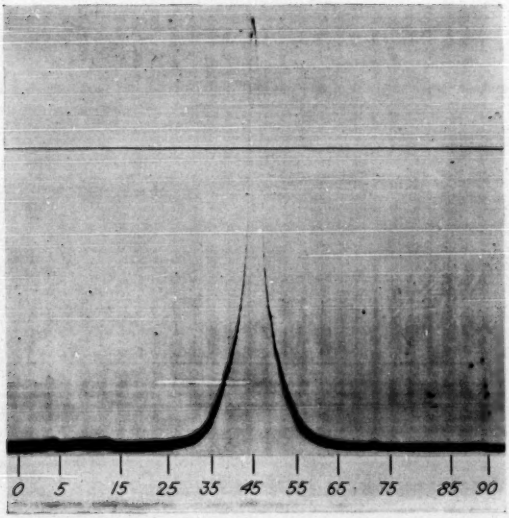
Photograph of detecting plate after exposure to a reflected beam of atoms.

Plate II.



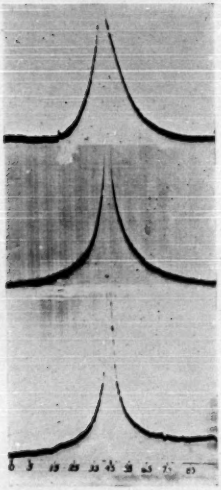
a *b* *c*

Plate III.



Distribution of reflected light incident at 45° on a roughly polished surface of nickel.

PLATE IV.



The variation of the intensity of the diffuse reflection with the temperature of the crystal. 45° incidence, upper 900° K., middle 600° K., lower 300° K.

PLATE V.

a. Freshly cleaved surface of LiF × 300.

b. Same after 3 hour bombardment by atom beam without ions being removed.

of a specular beam surrounded by a diffuse band having a maximum of intensity in the specular direction. Plate III is a densitometer record showing the type of angular distribution pattern which is obtained in the case of the reflection of light waves from a roughly polished surface of nickel at 45° incidence. In this case the mean vertical displacement of the actual surface from the average surface plane was found to be about 0.0003 mm. or about half a wave-length. This estimate is based upon the fluctuations in the reading of an optical lever having one pointed leg, as it was moved about on the surface, and from a microscopic examination of the surface. The distribution of the energy of reflected light shown by Plate III is very similar to the distribution of atoms reflected from the *LiF* crystal as illustrated in Plate IV, which happens to illustrate the phenomenon for three different temperatures, and the resemblance suggests that the diffuse atom reflection is likewise caused by an irregular surface roughness of the crystal. By analogy with the optical scattering pattern of Plate III, we expect the mean displacement of the surface ions from the average plane of the surface to be of the order of half the atom wave-length; that is, in the neighborhood of 0.3×10^{-8} cm. A displacement of this amount can doubtless be accounted for on the basis of the lattice theory as the amplitude of the thermal motions of the surface ions, although it is known that the ions in the interior of the crystal oscillate through somewhat smaller amplitudes.

Further and more conclusive evidence that the diffuse reflection of atoms from *LiF* is to be attributed to the thermal agitation of the surface ions lies in a comparison of the distribution curves shown in Plate IV. These give the angular distribution of atoms reflected at 45° incidence, with the crystal maintained at various temperatures. The lowest curve corresponds to 300° absolute temperature, the middle curve to 600° absolute temperature, and the upper curve to 900° absolute temperature. In order to reproduce all three curves in the same figure the specular peaks have been cut off, but in order to render them properly comparable the scales are adjusted so that those peaks, if shown, would all be of the same height above the outer flat portions of the curves. The increasing intensity of the diffuse band with higher tempera-

tures is very striking and it indicates a considerable change in the surface roughness over this range of temperatures.

The Effect of Ion Bombardment on the Crystal.—In the first work with the *LiF* crystals the specularly reflected beam was intense directly after the bombardment by hydrogen atoms was started, but its intensity diminished rapidly, and disappeared entirely after an exposure of one hour to the hydrogen atom beam. This fatigue in reflecting power was found to depend upon the electric field between the positive column of the discharge and the brass box, *B*, Fig. 20, for when a change was made in the connections of the transformer, which was used to excite the discharge, in such a way as to increase the field which accelerated positive ions through the slit in the discharge tube to the box, the fatigue time was diminished to a point which rendered it impossible to observe *any* specular reflection, although previously the spot formed by this beam had appeared visible to the eye in less than a minute. After an exposure to the beam of an hour or more under these conditions the crystal acquired a brownish tinge over the bombarded area. Accompanying these effects, a third phenomenon appeared which lead to a complete interpretation of the situation. If the crystal and the copper crystal holder were electrically insulated from the brass box, irregular fan shaped patterns appeared on the plate corresponding to a deviation of the beam of about 10° at the face of the crystal. Three facts were discovered which proved that this was not a true reflection. (1) Diaphragms inserted between the crystal and the plate showed that the entities responsible for the patterns had not passed over the line connecting the spots on the plate with the face of the crystal. (2) The positions of the patterns showed no regular dependence on the angle of inclination of the crystal. (3) The patterns appeared as long as the crystal holder was insulated, even though no crystal was present. These facts pointed to the theory that ions from the discharge tube were being drawn out by the strong electric field between the positive column of the discharge and the brass box, and that these ions were bombarding the crystal, thereby damaging its reflecting power and producing the brown discoloration. The charge accumulating on the crystal and crystal holder produced an electrostatic field which served to deflect other

ions from the beam into the irregular patterns observed on the plate. This theory was completely established when it was found that if the ions were removed from the beam by means of an electrode E, Fig. 20, charged to 5,000 volts, the life of the reflecting power was increased to three hours or more. At the same time, the irregular patterns disappeared and the crystal no longer became discolored by the exposure. Microphotographs of the cleaved crystal surface (Plate V) indicate that it is made up of small facets parallel to the 100 planes of the lattice. After bombardment, however, the surface is irregularly rough, as though the ions had smoothed off the edges of the facets. The energy possessed by a single positive ion after falling through 3,000 volts is sufficient to raise a cube 100 atoms on an edge to a temperature of 1000° C.; and, before this temperature is reached evaporation should be quite considerable. It seems probable that the observed effects can be accounted for in this manner.

In some later work a copper fin F was attached to the brass box so that the accelerating field between the two slits was asymmetrical and the ions were pulled away from the slit S_2. This device, in addition to the electrode E, increased the time during which the crystal remained a good reflector to about six hours, but longer exposures than this were still impossible. Some recent work of Compton and Van Voorhis [10] suggests that protons, after striking a metallic surface with a velocity corresponding to 5,000 volts are neutralized but reflected with a large part of the original energy. Perhaps it is the bombardment of the crystal by such high velocity neutral atoms that is responsible for the remaining fatigue in reflecting power.

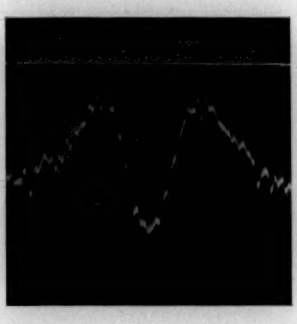
A Method for Velocity Selection of Atoms.—I have already remarked that the wave-length which corresponds to a moving particle depends upon its velocity. Since the beam of atoms used in the foregoing experiments have a wide range of velocity centering around an average value determined by the temperature of the gas, the phenomena observed are more complicated, and not so easy of interpretation as they would be were it possible to use a beam of atoms of uniform velocity. Some sort of velocity selector is desirable. Now the atoms have a

[10] Abstracts of the Washington Meeting of the American Physical Society, April, 1930.

very great speed, of the order of a hundred thousand centimeters per second, and, since they are not charged, we do not have available those means for sifting them into beams of different velocity which are available in the case of charged particles. It has, however, occurred to Dr. Johnson to make use of the fact that atoms of hydrogen act as little magnets which are known to turn themselves either in the direction of a magnetic field in which they are placed, or in the opposite direction. If a compass needle is floated on the sea it will tend to move towards neither the north pole, nor the south pole because the magnetic field is sensibly uniform in its neighborhood. If, however, it is placed in a region where the magnetic field is not uniform, then it will tend to move into the region of the strongest field. By passing a beam of atomic hydrogen through a non-uniform magnetic field whose direction is perpendicular to the axis of the beam, the atoms are pulled sideways, and suffer deflection from their original course. The amount of this deflection depends, of course, upon velocity of the atom, and upon the field gradient, so that if we should allow the atoms to strike a screen, whereas they might produce a fine spot in the absence of the magnetic field, they will be drawn out into a line in the presence of the magnetic field, into a sort of spectrum, each point of that spectrum corresponding to atoms of a certain definite velocity. It is only two or three years since this effect was discovered by Stern and Gerlach, and the actual demonstration of the shift produced by a magnetic field was considered at that time one of the most remarkable achievements of experimental physics. It is a significant example of the rapid advance which experimental technique makes that Dr. Johnson is now using this method not merely for showing the separation, but for actually sifting the atoms into groups of different velocities. Figure 21 is a densitometer record of the Stern and Gerlach effect obtained in Dr. Johnson's apparatus. The picture, represents, of course, vertically, the intensity of the atomic hydrogen beam, and horizontally, we have the distance parallel to the magnetic field. Each position measured along the horizontal axis corresponds to a definite atomic velocity, and the vertical distances are proportional to the numbers of atoms having the corresponding velocities. The peak cor-

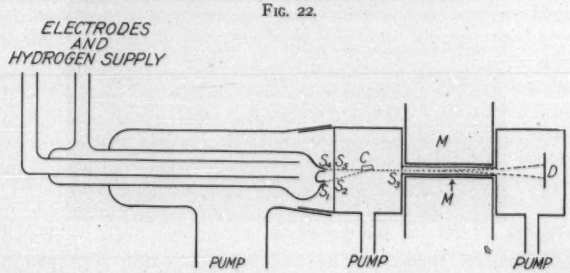
responds to the most probable velocity. The curve is symmetrical, the two symmetrical halves corresponding to the atoms which have been turned in the two mutually opposite directions in relation to the magnetic field. Figure 22 repre-

FIG. 21.



sents a diagram of the apparatus which Dr. Johnson is using in his first experiment with the velocity selector. The actual purpose of this experiment is to see whether the velocity distri-

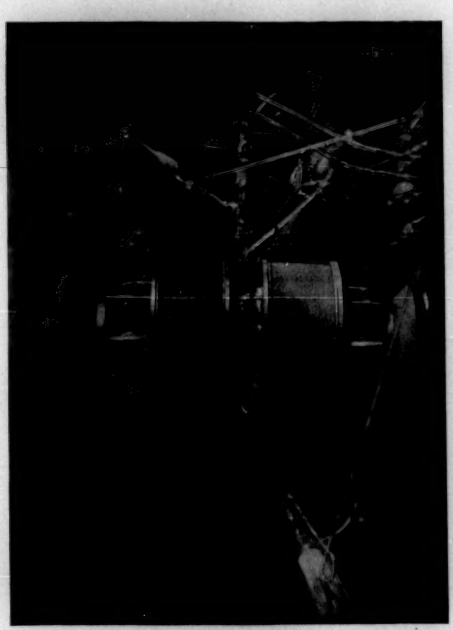
FIG. 22.



bution among the molecules of a beam is altered by reflection at the surface of a crystal. The beam under examination passes through the slits S_1 and S_2 and is reflected by the crystal, placed at an appropriate angle, through the slit S_3,

after which it passes along the path S_3D under the influence of a magnetic field in the direction of the arrow, a magnetic field which varies in strength in a vertical direction on the diagram. D represents the molybdenum oxide screen where the spectrum, as I may call it, of the atoms is spread out. The

FIG. 23.



densitometer record of the molybdenum oxide photograph, which takes the form shown in Fig. 21, gives the relative number of the atoms corresponding to each velocity. It is then possible to remove the crystal and pass another beam through the slits S_4 and S_5 to the screen D, and so obtain another photograph which may be compared with that ob-

tained by reflection from the crystal. In this way it is possible to compare the distribution of velocity after reflection with that for the direct beam. Figure 23 is a photograph of the actual apparatus in use. *M* is the large electromagnet which is used for producing the powerful and variable magnetic field. Unfortunately, it obscures the main portions of the apparatus so that they are not readily visible in the picture. The various glass parts in use are associated with the high vacuum pump, and accompanying appliances.

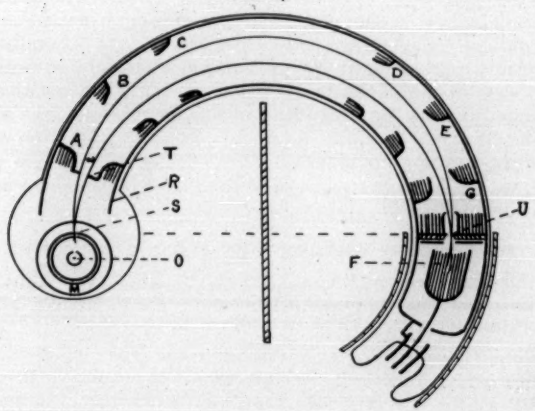
Of course, the ultimate purpose of these experiments which Dr. Johnson is performing upon the reflection of atoms from crystals, is firstly, the establishment of the evidence that atoms are reflected as waves would be reflected, and secondly, the determination of as much information as possible concerning the way in which atoms behave when their velocities are changed by passing near other atoms, in this case, the atoms of the crystals. A complete knowledge of the situation would amount to the equivalent of knowledge of what a few years ago, we would have spoken of as the forces between the atoms at collisions.

THE PASSAGE OF ELECTRONS THROUGH THIN METALLIC FILMS.

Although solid matter appears such substantial stuff, it is, in its own scale of magnitude, more vacuous than almost anything that we customarily think of in the large scale things of life. Thus an atom of hydrogen has been regarded as a central nucleus with an electron revolving around it, the relative magnitudes being such that if I should draw the nucleus as large as one of the letters of this page, I should have to draw the electron 13 ft. in diameter and place it on a circle about 300 miles away. The hydrogen atom is thus a very empty thing and a similar remark may be made with regard to all of the atoms of which matter is composed. Even when these atoms are crowded together as in a solid, the spaces between things like electrons and protons are very large compared with the sizes of those entities themselves, so that the space occupied by the matter is very much filled up only in the sense that a cathedral piled with chairs is filled up. There is very little room for an elephant to walk about, but plenty of room for a fly. It is on account of this highly tenuous nature of matter

that it is possible to shoot things like α-particles and electrons through even relatively thick films of metal, and the story of what happens to them in passing through such films has always been of considerable interest. It is of interest because the history of what happens is determined by the action of the individual atoms upon the particles as they pass through, and so contains in part a clue to the nature of those actions. Dr. Mildred Allen has been carrying out an experiment designed to investigate some of these questions. Briefly, the

FIG. 24.



plan is to shoot a beam of electrons of constant velocity through a film of gold, and ascertain how the beam spreads, how the velocity of the electrons is changed in passing through the film, and how the change of velocity depends upon the angle between the initial and final direction of the electron beam. A well-known method for measuring the velocity of an electron consists in allowing its path to be bent into an arc of a circle of known radius by means of a magnetic field, and then determining the velocity from a measurement of the magnetic field.

Fig. 24 represents a diagram of Dr. Allen's apparatus.

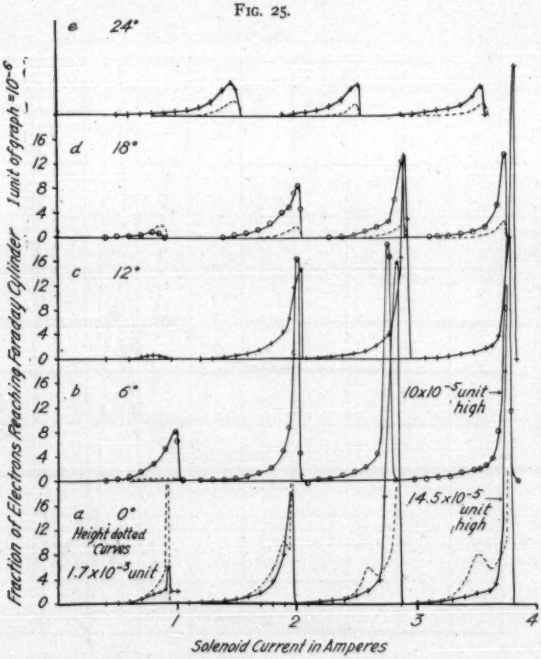
The electrons are obtained from a heated filament at *O* and pass through the slit *S*. The angle of the beam is limited by the opening *T* and the apparatus is arranged so that there is a magnetic field which is perpendicular to the plane of the paper and which, consequently, bends the electron paths into half a circle causing them to come, as is well known, to a focus at a point *U* diametrically opposite to the slit *S*. The electrons are allowed to pass into the metal cylinder *F*, known as a Faraday cylinder, which is connected to a suitably arranged electrical measuring instrument so that the current of electricity passing through the slit *U* may be measured. The velocity given to the electrons is determined by an electrical difference of potential between the filament and the parts which are in connection with the slit *S*. The magnetic field is produced by a current in an external solenoid. It is very important that the electrons shall suffer no deviation by the magnetic field until they have obtained the full velocity to be given them by the electrical potential difference. In other words, it is very necessary that the space between the filament *O* and the slit *S* shall be absolutely free of magnetic field. If it is not, then, when the magnetic field is varied, for the purpose of bringing on to *U* electrons corresponding to different velocities after emergence through the film, the results will be affected in a manner difficult to interpret. For the original beam of electrons coming from the filament will fail to strike the slit *S* in a manner independent of the magnetic field. For this reason, an additional solenoid made out of metal, in the form of a ribbon, was caused to surround the filament, and is shown in the plan by the annulus *M*. This solenoid was kept at the potential of *S*. A suitable current passed through it served to annul, in its interior, the magnetic field produced by the large external solenoid The compensation was preserved, of course, for all values of the current in the larger solenoid, so long as the ratio of the current in the two solenoids was kept constant. The smaller solenoid, and the filament, were mounted as one unit which could be turned about the slit *S* as an axis by means of a ground glass joint at the end of a tube sealed to the semicircular tube shown in Fig. 24, perpendicular to its plane, and so that its axis passed approximately through *S*. The object of this arrangement was to enable one

to investigate the change of velocity of the electrons for different angles between the incident and the emergent beams. In all cases, as already pointed out, the emergent beam was limited to an angle determined by the slit T. This angle amounted to about 3.5°. We shall refer to it as the angle ω. The vanes A, B, C, D, etc., served simply to cut out any stray electrons which might be scattered from the walls. Of course, all sorts of minor precautions, which it would be tedious to enumerate, had to be taken. One rather interesting precaution concerned the fact that the electrons which struck the regions around the slit U produced X-rays which entered the cylinder F causing electrons to be ejected from it, and leading to a rather mysterious and spurious effect. This difficulty was eliminated by thickening the walls of the slit U by means of lead strips, so that the X-rays generated by impact of the electrons upon these walls were unable to pass through to the Faraday cylinder.

The general plan of the experiment was then as follows. The ground glass joint was first turned so that the line joining the filament to the slit S was inclined at some definite angle θ to the axis of the beam which emerged through the slit S, and succeeded in passing within the angle ω above referred to. A known difference of potential was then applied between the filament and the slit, in the first place with the film absent, and the current to the cylinder F was measured for various fields in the large solenoid, with, of course, corresponding compensating fields in the small solenoid. These measurements gave data on the number of electrons emerging through the slit in the little angle ω, with various velocities as calculable from the magnetic field in the large solenoid. Experiments of the foregoing kind were first performed for any given angle θ, with the film absent. Then the film was brought into position by means of a device operated magnetically by the aid of an external solenoid and the experiment was repeated. The whole series of operations was then repeated for various angles θ, and for various potentials applied between the filament and slit S. In the ideal case, the curve for a Faraday cylinder current plotted against the magnetic field would be, for the film absent, one very sharp peak with zero ordinates elsewhere. In practise, however, curves of the kind indicated by the

dotted curves at 0° in Fig. 25, were obtained. It was found, subsequently, that the humps to the sides of the main peaks were attributable to electrons which had struck one of the

FIG. 25.

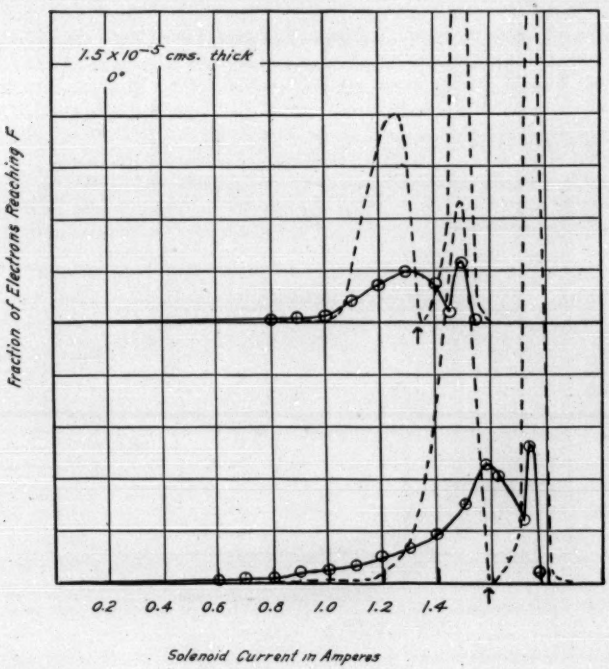


Full curves give results with gold films.
Dotted curves give results without films.
Total current for *a*, *b*, *c*, *d* 5 × 10^{-4} ampere, in *e* 2.5 × 10^{-4} ampere.
Thickness of film in *a*, *b*, *c*, *d* 6 × 10^{-5} cms., in *e* 7.5 × 10^{-5} cms.
One ampere in the solenoid gives a field of 22.4 gauss, which corresponds to a velocity of approximately 4.6 KV or 0.132 cms. per sec. where *c* is the velocity of light. In *a*, *b*, *c*, *d* the zeros of the successive curves are shifted 0.6 ampere to the right in order to separate the curves better, in *e* this shift is 0.8 ampere. The origins of ordinates for the successive curves are indicated, but, in order to conserve space the lower curves are allowed to run into the spaces of the upper curves.

vanes, the vane *C* in fact, and without loss of velocity, had been deviated by the magnetic field so as to pass through the slit *U*. The number of electrons participating in this spurious

phenomenon was exceedingly small, as may be evidenced from the fact that, on the scale of plotting indicated in Fig. 25, the main peak would have a height of four feet. As a matter of fact, the currents obtained with the film present, were so much

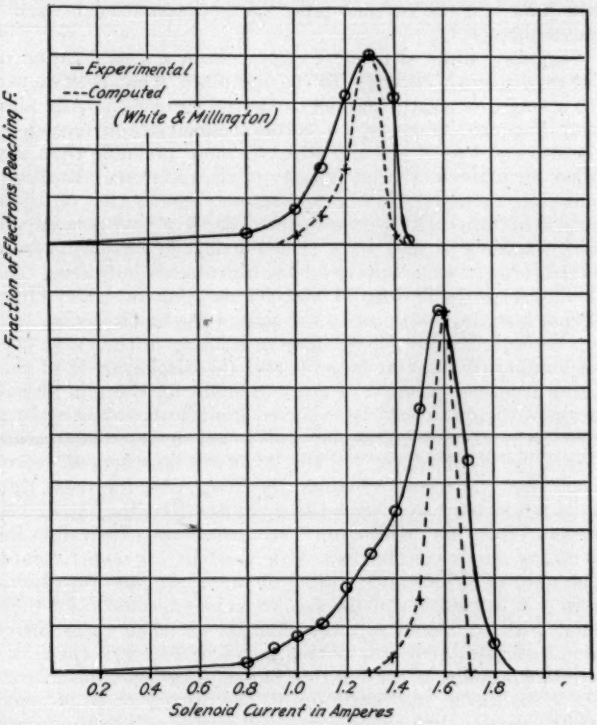
FIG. 26.



smaller than those obtained without the film that, if the scales were adjusted so that the same maxima were obtained in each case, the side humps referred to would in all cases be negligible. Figures 25 and 26 represent the experimental results obtained. Figure 25, *a*, *b*, *c*, *d*, and *e* corresponds to a

film of a thickness approximately 6×10^{-6} cm., while Fig. 26 corresponds to a film of thickness 1.5×10^{-5} cm. The thicknesses of the films were measured by measuring their optical

FIG. 27.



transmission and calculating the thickness from a formula developed according to the electromagnetic theory. In each case the dotted curve represents the experiments performed with the film absent, and the ordinate represents the ratio of

that portion of the electron beam which had passed through the angle ω, and had been collected by the Faraday cylinder, to the total electron beam passing through the slit S, the latter quantity being measured by allowing the whole current passing through this slit to be collected by the copper shield R, which was joined to the earthed point of the apparatus through a galvanometer.

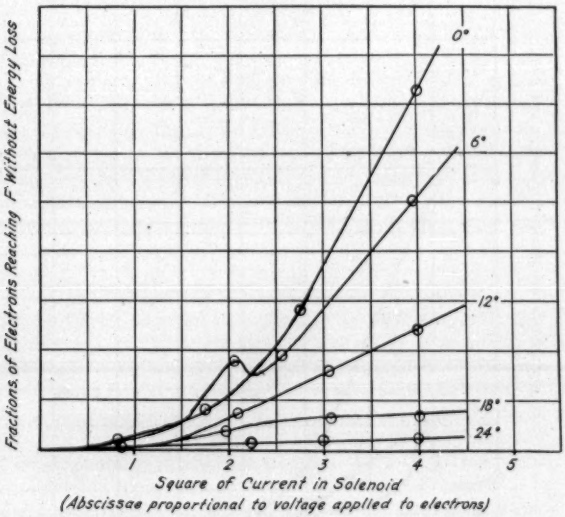
Several points of interest emerge from a consideration of the experimental curves. In the first place, it has been known for a long time that when electrons pass through a metal film, they lose on the average a certain velocity, and moreover, there is one loss of velocity which is more probable than any other for a given original velocity of the electron. An examination of the curves in Fig. 25 however, reveals that for these very thin films, of thickness of the order 6×10^{-6} cm., curves with the films present show their maxima in the same places as the corresponding curves for the film absent, indicating that the most probable loss of velocity is zero for these films. When, however, we come to the case of the much thicker film represented by Fig. 26, we observe a hump in the curve corresponding to the film present, and the displacement of this hump from the position of the maximum for the film absent agrees with what might be expected from former observations. The form of this particular curve has a very interesting theoretical significance. In Fig. 27 it will be observed, moreover, that the results obtained by Miss Allen for these thin films agree very well with the formula given by former observers White and Millington,[11] and based upon their data for electrons much swifter than those used in her experiments. The data of White and Millington were obtained for aluminum. A calculation of the results to be expected from their data, with constants suitably changed to make them correspond to gold, gives the dotted curve of Fig. 27, where the ordinates represent the fraction of the electrons transmitted. For comparison, the maximum of the dotted curve is made arbitrarily equal to that for the full curve, which represents the data obtained by Dr. Allen.

Another interesting feature of the data is obtained by

[11] P. White and G. Millington, "The Velocity Distribution of β-particles after Passing through Thin Foils," *Roy. Soc. Proc.*, A, Vol. 120, pp. 701–726, 1928.

plotting the height of the peak against the potential applied to the electrons. The results are represented in Fig. 28. I wish particularly to call attention to the curve for $\theta = 6°$. It will be observed that there is a general increase of the height of the peak with increase of voltage, indicating that the number of electrons which succeeded in getting through the film within

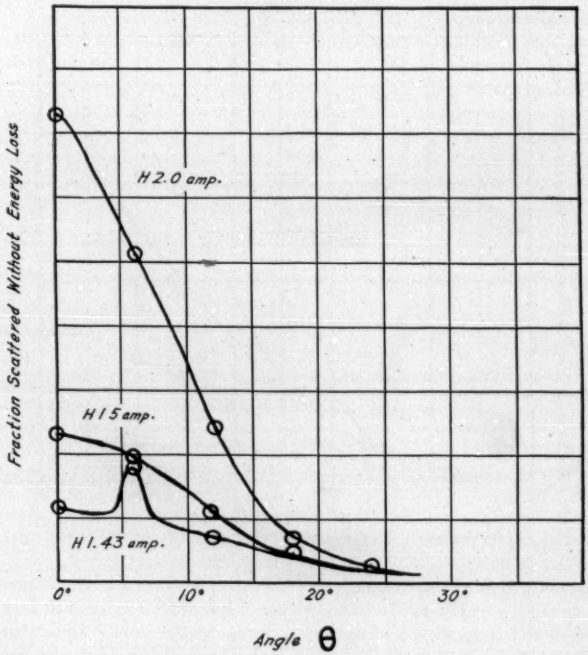
FIG. 28.



the angle ω, without change of velocity increased with voltage. However, at the particular voltage 9 kilovolts (current in large solenoid, 1.43 amps.) there is a hump in the curve, indicating that the angle $\theta = 6°$ is particularly favored for electrons having the velocity corresponding to 9 kilovolts. It is a very significant fact that this velocity corresponds to the particular electron velocity which, according to the measurements of G. P. Thomson, for gold, gives a diffraction ring at 6°. If we concentrate our attention upon those electrons which get

through without loss of velocity, we shall find them distributed in angle for a given voltage, or distributed in voltage for a given angle. For every voltage there would be a particular angle for which there was a maximum of the electrons transmitted without loss of velocity, and for every angle there

FIG. 29.



would be a voltage which gave a maximum in the curve of transmission without loss of velocity. As stated above, it happens that the relation between the angle $\theta = 6°$ and the voltage corresponding to the little hump is just such as would be expected from the experiments of G. P. Thomson on

diffraction of an electron beam. It is not unlikely that if the data had permitted of a more close spacing of the points in Fig. 28, these maxima would have shown themselves in the other curves, particularly those for smaller angles, as well as in the curve for the 6° angle. The phenomenon referred to above is shown from another aspect by Fig. 29, in which, for different voltages, the intensity of the electron beam is plotted against the angle θ. Here we have the phenomenon showing itself as a maximum of transmission for a particular angle ($\theta = 6°$) corresponding to the velocity given by the current 1.43 amperes in the large solenoid. The hump is represented by only one point, but is nevertheless definite in the curve labelled $H = 1.43$. It is hoped that these experiments on the passage of electrons through thin films may suggest important ideas with regard to the mechanism of the process, particularly in the case of very thin films, and that they may point the way in which further experimentation may be most advantageously undertaken for determination of the facts of this most important phase of physics.

MASS NUMBERS OF ISOTOPES AND ALLIED PHENOMENA.

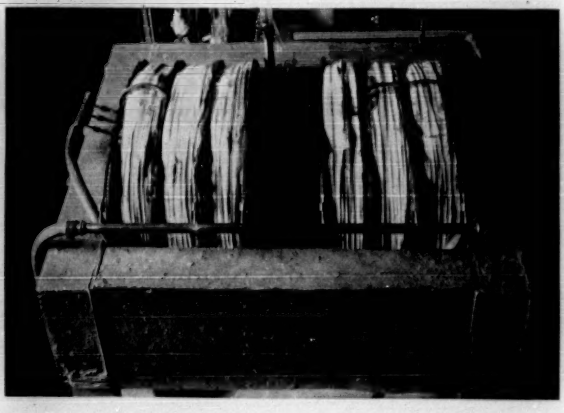
I now turn to certain experiments which Dr. Bainbridge has under way, and which have to do with the measurement of atomic weights of isotopes. There was a time when we believed that each of the so-called elements was composed of atoms which were all alike, the atom of any one element having always the same atomic weight. We now know, however, that corresponding to any one element there may be several atoms differing slightly in atomic weight, or mass number as it is sometimes called. On the Bohr picture, all of these atoms representing the same element are alike in the sense that they possess the same nuclear charge. We can, however, vary the atom and retain the same nuclear charge provided that we add to the nucleus a proton and electron together, so that they neutralize each other as far as charge is concerned. The result is to produce something with a changed weight, but something which, as regards all phenomena in which the nuclear charge only is concerned, acts in the same manner as before. The orbit of the electron which revolves around the nucleus would know practically nothing of the change made by

the addition of a proton and an electron simultaneously to the nucleus; and, since our knowledge of the situation leads us to believe that chemical properties, and almost all of the activities exhibited by the atom depend upon the behaviour of the orbital electrons, those atoms which differ from one another only in the way I have described, were separable only with difficulty, since they acted alike as regards all chemical processes which might be invented to separate them. Only by a process which made direct use of the differences of the masses of the nuclei was it possible to separate them. Atoms which differ from each other only in the matter of the weight of the nucleus without difference of the nuclear charge, are spoken of as isotopes of one another. According to the theory of radioactivity, a substance like radium is in a continual state of disintegration. The nucleus occasionally shoots out an alpha particle with the result that the residue represents something other than the radium itself,—it represents a gas—radium emanation. An atom of this gas in turn shoots out, eventually, an alpha particle, changing to something else, and so on. Now, we have reason to believe that certain of the so-called non-radioactive elements are radioactive in slight degree, and that the various isotopes which we find associated with the same elements in certain cases, at any rate, are apt to be related in the sense that some are the parents of others.

If a charged particle is shot into a uniform magnetic field, it will, of course, traverse a circle whose radius depends upon the mass of the particle, upon its charge and upon its velocity, and a small angled cone of such particles emerging from a point will be caused to converge approximately to another point diametrically opposite to the first point. I have already referred to this matter in connection with Dr. Allen's experiments, where the principle was used to compare different electronic velocities. It may also be used to compare the masses of different charged particles. In the case where the source of the particles is a slit, the particles focus themselves into a line after describing the circular arc; and, in many cases they may be recorded upon a photographic plate. In the case of a number of charged particles of different masses, we should obtain, on the plate, a series of lines corresponding to the different types of particles. Of course, all of this is well

known, and, in one form or another, it has served as a means of ascertaining the atomic weights of isotopes for many years. In the experiments of Dr. Aston, of Cambridge, England, the plan was not to bend the particles to a complete circle, but to allow them to suffer only a small deviation through the agency of an electric and a magnetic field in tandem and then by suitable means, measure that deviation and estimate the masses of the particles. There are certain advantages inherent in making the particles describe a complete semicircle,

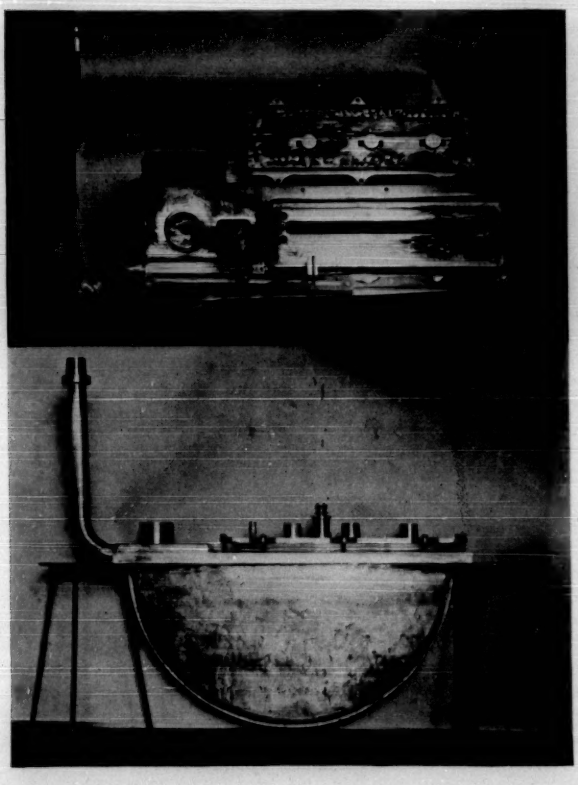
FIG. 30.



and this plan has been used in the experiments of Dr. Dempster of the University of Chicago. However, it is not possible to obtain very accurate results by this means unless the area of cross section of the magnetic field is very large so as to permit the particles to describe circles of large radius. In Dempster's experiments, the area of the poles of the electromagnet used for producing the field was quite small. We have had constructed for the purpose of isotope measurements, a very large electromagnet which is shown in Fig. 30. Dr. Bainbridge's first problem is the isolation, by this apparatus, of the isotopes of tantalum, molybdenum, tungsten, thorium, and uranium,

which isotopes so far have not been isolated; and he proposes to determine the relative amounts of the various isotopes

FIG. 31.



Plan

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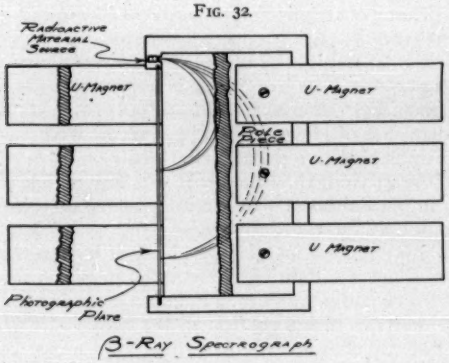
which are present in the elements of each of these substances. Our knowledge of the theory of radioactive disintegration tells us how to get some clue as to the degree of stability of the

various isotopes by knowledge of the relative amounts of each present, and one of the primary purposes of this investigation is to arrive at information of this kind. Also, by the determination of the relative amounts of the constituent isotopes of an element it is possible to determine the average atomic weights of the atoms very accurately. A second investigation planned with this large magnet, is the determination, with the highest possible accuracy, of the atomic weights of certain definite isotopes associated with potassium. It has been surmised for some time, and has recently been shown without question, that potassium is radioactive and emits high speed negative electrons, that is to say beta rays, in the process of disintegration. It is believed that the radioactivity of potassium is due to one of its isotopes, one having an atomic weight 41 in terms of hydrogen as a unit. The belief rests upon certain experiments of Hevesy, who by starting with a sample of potassium was able to separate it into two samples, one richer in potassium 41 than the other. It was found that the specimen rich in potassium 41 was the more radioactive to just the extent expected on the assumption that potassium 41 was responsible for the radioactivity. Now if it is potassium 41 which is radioactive, then, since no alpha particles accompany the radioactivity of potassium, we should expect that the atom 41 would emit, in disintegration, a beta ray, with the result that its nuclear charge would change. Its mass would not appreciably change unless it emitted an alpha particle also. Thus we should expect the potassium to change to an element which had one unit more nuclear charge but which had practically the same weight. Such an element would be calcium. It is therefore of interest to see whether in a mineral containing a mixture of potassium and calcium, there is to be found, after removal of the potassium by chemical means, an isotope of calcium with a weight corresponding to 41. This is one of the problems which Dr. Bainbridge is attacking. Figure 31 represents a picture of the chamber in which the isotopes are to travel their circular paths. It is made so that it can be evacuated, and contains many parts associated with the photographic and electrical recording systems which it is unnecessary to describe.

Another problem having to do with the radioactivity of

potassium is the determination of the rate at which the potassium decays. The rate is probably very small. Uranium, which is enormously more radioactive than potassium lives so long that any quantity of it takes six thousand million years to become reduced to half of its amount, and the rate of decay of potassium is probably very much smaller than this. Its half life is about a million million years. We can determine the number of atoms breaking up per unit of time in any assigned number of atoms, and determine the rate of decay, if

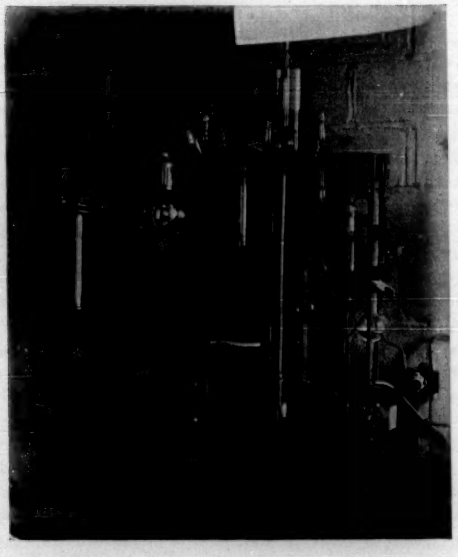
FIG. 32.



we can determine the number of electrons which are emitted from an assigned weight of potassium per unit of time. We can measure the electrons by measuring the ionization which they produce in a gas contained in a suitable container, provided that we know the ionization produced by a single beta ray of known velocity, and this information is available from published data. So Dr. Bainbridge has undertaken the determination of the velocity of the beta rays from potassium. For this purpose he is using another apparatus similar in principle to that involving the large magnet, but much simpler in form. Figure 32 is a diagram of the apparatus. Instead of having a large magnet there is a number of small permanent magnets arranged so as to give an extended pole area. The poles of the magnets are sufficiently extended to insure that the

particular circle which the electrons wish to describe will fall within the region where the magnet produces a field. As is well known, it is possible to calculate from the radius of the circle obtained, the product of the mass of the electron and its velocity, so that, knowing the mass, we can deduce the velocity. The electrons are being detected by means of a

FIG. 33.



photographic plate. In view of the very weak radioactivity of potassium several months are necessary to obtain a measurable photographic image, and during the whole of this time, it is necessary to keep a vacuum on the apparatus so as to prevent scattering of the electrons by the air inside. Fig. 33 is a picture of the actual apparatus. It is so arranged that there is a number of test photographic plates which can be ab-

stracted from time to time without interfering with the main plate. The purpose of this is to see how the experiment is going on, and ascertain that nothing unfortunate has happened to spoil the final result to be expected from the main plate. One naturally does not wish to have to wait several months for nothing.

Then, turning once more to the large magnet, which is associated with the mass spectiograph, as it is called, Dr. Bainbridge proposes to utilize it for the determination of the masses of the isotopes with the highest degree of accuracy possible. A primitive view of the situation would call for the masses of all of the elements and isotopes as being integers, with hydrogen as unit. However, when the various protons and electrons that go to make a nucleus come into one another's vicinity, they affect one another in such a manner as to cause some of the mass to disappear. The mass of ten protons and ten electrons when separated from each other is greater than when they are in close proximity. This mass defect, as it is sometimes called, is very small. It has been measured by Dr. Aston for many of the elements. Dr. Bainbridge is planning to measure it for many elements for which it has not been measured, and he is trying to improve the accuracy for those elements for which it has already been measured. The importance of this mass defect lies in the fact that, in terms of it, we can calculate the amount of energy which will become available in constructing an atom out of protons and electrons. To give an idea of the considerations involved, I will call your attention to the fact that we could make a single atom of helium out of four atoms of hydrogen. In constructing the helium, however, we should find that, for every gram of hydrogen originally taken, there would be a loss of 0.0075 gram of material as a result of the formation of the helium. Now we know from electrodynamics and from relativity considerations alike that loss of mass is synonymous with departure of energy from a system, the change of energy being equal to the change of mass multiplied by the square of the velocity of light. The amount of energy which would become available by the formation of one gram of helium from one gram of hydrogen would be enough to raise about 4×10^6 lbs. of water from the temperature of melting ice to the boiling

point. Thus from the so-called mass defect obtainable from an accurate knowledge of the atomic weights of the isotopes, we are able to form estimates of the energy stored up in the various atoms, and of the changes of energy which would be involved in any transmutation of the elements.

A STUDY OF A CERTAIN BAND STRUCTURE IN THE SPECTRUM OF MERCURY.

I have already called your attention to the fact that the emission of light on the Bohr theory is supposed to occur by transitions between different energy states corresponding to different electron orbits. Now there is another kind of transition which plays a part in atomic phenomena. Suppose that we think of a molecule composed of two atoms, and instead of taking a detailed view of all of its electronic orbits, let us think of these two atoms in the simplest possible manner, as something like the two ends of a dumbbell. This whole system can have energy resulting from the vibrations of the two ends of the dumbbell along the axis, or it can have energy resulting from the rotation of the dumbbell about its center of gravity. The quantum theory has given a means of showing how this situation can give rise to radiation. It has established principles according to which only certain energies of rotation of the dumbbell are possible, and only certain energies of vibration are possible, and when the dumbbell passes from one of these energy states to another, radiation is emitted. The radiation emitted in this way is of very much lower frequency than that corresponding to ordinary light, and the distribution of the energy states are such that the actual frequencies emitted differ very little from each other, so that the lines produced in a spectrum of this kind are all very close together and produce the appearance of a band, so that in many cases, it was a long time before these bands became actually resolved into separate lines. When only these rotational or vibrational energy states are involved, the bands are in the infra-red. It is possible to get bands in regions of the spectrum of relatively short wave-length, and even in the ultra-violet. Here we have a transition composed of the composite effect of, let us say, the return of an electron of the atom from some outer orbit, to its innermost orbit, and at the same time, a change of one of the vibrational or rotational states of the dumbbell

which constitutes the molecule as a whole. The atom combines these two phenomena together into one, and sends out a frequency of radiation appropriate to the total change of energy involved. Now, another atom may behave exactly like the one that I have just described, in the sense that the electronic jump from some outer orbit to the innermost orbit is the same for each, while the change in the vibrational or rotational quantum state may be different. In view of the small energy change involved in a change of a vibrational or a rotational quantum state the total change of energy resulting from the composite transition will be almost the same in the second case as in the first case, so that the spectrum lines obtained in the two cases will be very nearly of the same frequency. We may in this way obtain a whole number of lines which are very close together, and form a band. Each of these lines may be regarded as the result of what we may call an atomic transition superposed upon a molecular transition, the molecular transition being, as it were, of such small effect that differences in the molecular transitions concerned make very little difference in the frequency of the emitted radiation. Now, knowing the nature of the atoms, it is possible to calculate the kind of spectra which may be expected in this manner. In mercury we have a certain band in which the separation of the members of the band is much too great to be accounted for by any such state of affairs as I have indicated; and, consequently, the existence of this band presents a problem in molecular physics which, until it is settled, leaves us in doubt as to the correct mechanism of the whole phenomenon. Now a certain theory has been developed as to the origin of this band in mercury vapor. It is a wave mechanics theory, and it is far too involved for me to enter upon now. Suffice it to say that the theory possesses the power to indicate the intensity of the lines of which the band is composed, if we know the wave-lengths of the various constituents of the band. Dr. Nielsen is performing an investigation in which he is photographing the bands with a large spectroscope. The photograph will be submitted to an analysis by the densitometer, so that he will be in a position to determine the relative intensities of the various lines and so settle this question as to the applicability of the theories proposed.

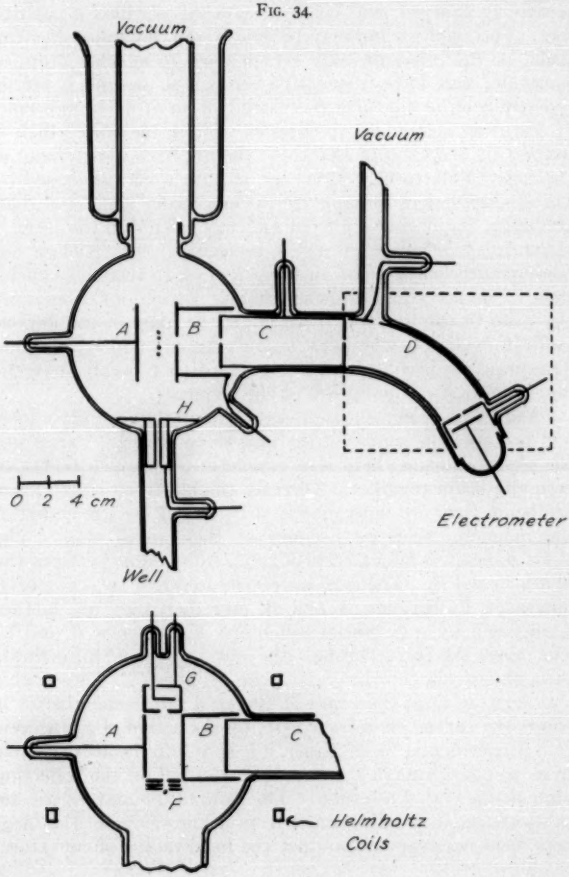
ON THE NATURE OF IONS IN MERCURY VAPOR.

Another investigation under way in the hands of Dr. Nielsen, concerns the nature of negative ions in mercury vapor. If an electron is detached from an atom, the remainder is positively charged, and constitutes what is called a positive ion. The negative ion may be simply the remaining electron itself, or that electron may attach itself to another atom or molecule, and form a negative ion whose weight is consequently comparable with the weight of an atom or molecule. It has been customary to suppose that in mercury which is ionized by a stream of electrons, the negative ions remain in the form of electrons. However, certain work performed by Dr. Nielsen before he came to this laboratory suggested that, probably, the negative ions in mercury existed in the form of electrons attached to atoms or molecules. Dr. Nielsen has consequently carried out an investigation to test this conclusion. The investigation proceeded by setting out to measure the mass of the ion; for, if we know the mass of the ion, we know immediately whether it is an electron or a mercury atom. The principle involved is analogous to that involved in the determination of the masses of the elements.

A stream of electrons is passed through the mercury vapor, and becomes the source of the ions to be tested. Parallel to the electron beam there is a magnetic field which serves to hold the beam together. Directly the electrons try to leave the beam they are immediately driven back by the action of the magnetic field, on account of their small mass. The electron beam is indicated in Fig. 34, by the dots between the plates A and B. The ions are accelerated first by a potential difference V_c between A and B, and then they are further accelerated by a potential difference V_a between B and C. The ions pass first through the slit in B, and afterwards through two slits on the ends of the cylinder C. These latter slits serve to limit the beam of ions to a thin pencil, before it enters the curved chamber where, by the action of a magnetic field perpendicular to the paper, it is bent into the arc of a circle so as to pass through the lower slit and fall on the collecting plate at the end of the tube. The ratio of the mass of the ion to its charge may be obtained from a knowledge of the magnetic field necessary to produce the fixed radius of curvature.

The net result of these experiments has been to show that the negative ions predicted by Dr. Nielsen, do actually exist. The path to this conclusion has not been as easy as might at

FIG. 34.



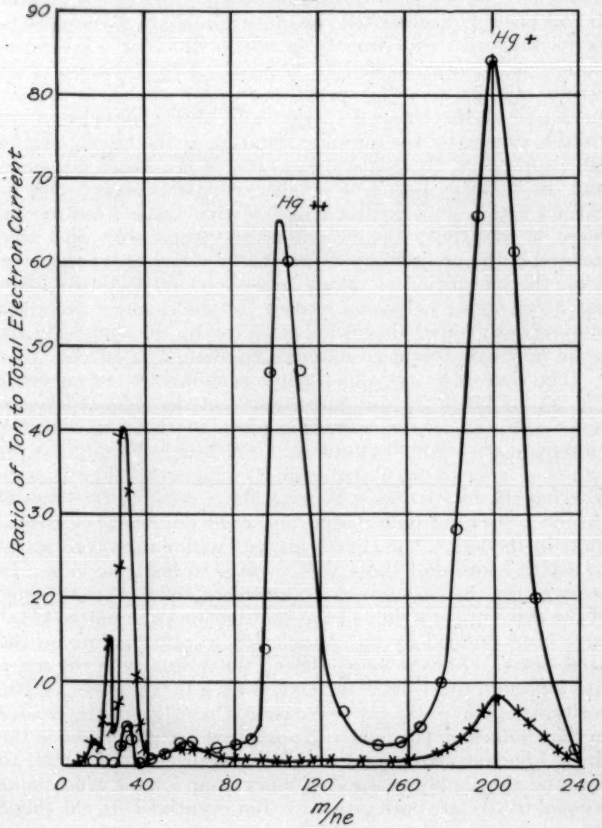
first sight be supposed. In the first place, the charges resulting from the separation of the ions produced by the electron beam cause an uncertainty in the magnitude of the difference of potential through which the ions fall by the time they reach the analyzing magnetic field. In the preliminary experiments which Dr. Nielsen performed, this fact produced some trouble. It was possible to eliminate the uncertainty which it caused by performing two experiments in which different accelerating potentials V_a were applied to the ions. A combination of the results of the two experiments gives both the ratio of mass to charge of the charged carrier, and also a measure of the trouble caused by the undesired charges in the beam. In his later apparatus, Dr. Nielsen was able to use lower pressures, and an electron beam of smaller current density, and to extract ions from a greater length of that beam so as to conserve a sensitivity of measurement comparable with that secured in the preliminary experiments. With this apparatus, while the precaution of taking measurements with two different accelerating fields was taken in the manner described above, it was found that fields produced by the charges in the beam no longer produced measurable disturbing effects.

The content of the experiments is shown by the curves in Fig. 35, in which the ordinates represent the ratio of ion currents collected at the collecting plate to the total electron current in the beam of electrons. The abscissæ represent the values of m/ne, as calculated from the magnetic field necessary to bring the ions to the collecting plate, m being the mass of the ion, e the electronic charge, and n the number of electronic units in the ion. The curves marked with circles correspond to positive ions and those with crosses to negative ions. In order to get the curves into a convenient space, the ordinates of the three upper points of the positive ion peak marked Hg^+ have been divided by two in relation to other points on the same curve. For the same reason, the ordinates of the negative ion curve have been multiplied by a factor of 800. The positions of the peaks give, of course, the ratios of the masses to the charges on the ions. We see that for positive ions the singly charged mercury atom ion for which m/ne is equal to 200, and the doubly charged mercury atom ion for which m/ne is equal to 100, are both present. For negative ions, the single

ged mercury atom ion is present. The last named fact represents the conclusion which Dr. Nielsen set out to test.

It will be observed that certain other peaks show themselves. These have, for both negative and positive ions, the

FIG. 35.



values 29, 20 and 12, respectively, for m/ne. They probably arise from the picein wax used in the glass joints of the apparatus. The 29 ion corresponds, probably, to carbon monoxide, and the 12 ion to carbon.

Were it not for such considerations as are involved in the finite width of the slits in the apparatus, etc., the curves in Fig. 35 would appear as very narrow peaks with zero ordinates at all points between. It is on account of these subsidiary considerations that the peaks become spread out to a finite width. A consideration of the matter shows that the number of ions associated with the value of m/ne given by one of the peaks is approximately proportional to the area of the curve associated with the peak divided by the corresponding value of m/ne. If then we know the relative efficiencies of electron ionization corresponding to positive ions for CO and Hg, we can calculate, from the relative areas of the peaks associated with CO^+ and Hg^+, the amount of CO present. Since the CO molecule contains the same number of electrons as the nitrogen molecule, it is probably safe to assume that the ionization efficiency for positive ions for CO is of the same order of magnitude as that for N_2 which is known from published data, as is also the ionization efficiency corresponding to Hg. Dr. Nielsen was thus able to calculate the relative amounts of CO and of mercury present. Now the efficiency of electron attachment for negative CO ions is known from published data, so that since the relative amounts of CO and mercury vapor present are known, it is possible to calculate what value of the efficiency of electron attachment for mercury ions is necessary in order to account for the relative numbers of negative CO ions and of negative Hg ions calculable from the corresponding peaks on the curve of Fig. 35 for negative ions. In this manner, Dr. Nielsen was able to determine the efficiency of electron attachment for Hg^- ions. He expresses his results as what is called the attachment coefficient for an electron for the formation of Hg^- ions, i.e., the average number of impacts which an electron suffers in mercury vapor before becoming attached to an atom of the mercury to form a negative ion. He finds for this quantity 6×10^{10}. For comparison, it is of interest to observe that the known attachment constant of an electron for the production of negative ions of CO is 1.6×10^8.

EXPERIMENTS ON THE THERMIONIC AND PHOTOELECTRIC WORK FUNCTION.

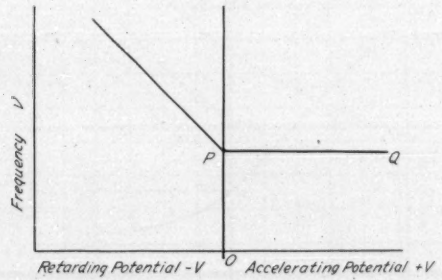
I now turn to certain experiments which have been performed by Dr. W. B. Nottingham, having to do with the emission of electrons from metals under the influence of light, and particularly with the influences which come into play upon the electrons when they depart from the metal surface. An electron endeavoring to leave a metal surface experiences forces at the surface which hinder its departure. Were it not for these forces, it would be unnecessary to heat the filament of our radio tubes in order to extract from them the electronic currents which perform the purposes of the amplifier. As a matter of fact, we should get far too much current, far more than we want, even at room temperature. Owing to the fact, however, that these forces exist at the surface of the metals, only those electrons which have sufficient velocity are able to escape, and the number having the necessary velocity is increased, of course, with increase of temperature. In the photoelectric effect, when we send light of a definite frequency ν upon the metal, we think of it as giving energy to an electron which absorbs the light, the amount of energy being equal to $h\nu$, where h is Planck's constant. If this energy is enough, the electron may be able to leave the surface of the metal, and if it does so, it may be expected to leave with a kinetic energy $\frac{1}{2}mv^2 = h\nu - W$, where W is the amount of work which is done on the electron by the surface forces, during its departure. W is called the work function of the surface. It is possible to measure the kinetic energy with which the electrons emerge, and if the frequency ν of the light is such that $h\nu$ is equal to W, then the electrons will just succeed in emerging with zero kinetic energy. The procedure is to allow the electrons to emerge from the metal A and travel towards a collecting plate B under the influence of an electric field which is produced by a difference of potential V between A and B. By adjusting the difference of potential V so as to retard the electrons in their journey to plate B, it is possible to prevent any of them from getting to B, and under this condition we have

$$Ve = h\nu - W,$$

where e is the magnitude of the electronic charge, since the quantity Ve is a measure of the kinetic energy of an electron

when it emerges from the metal. It must be understood that V here represents the difference of potential between A and B corrected for what physicists will recognize as the contact difference of potential. If we plot the frequency of the light against the quantity V, we get of course, a curve, the slope of which is e/h. All of this has been very well known for many years. At the point where V is equal to zero, we have $W = h\nu$. Suppose now we should actually reverse the potential V so as to assist the electrons after they come out from the metal. A simple view of the situation would not lead us

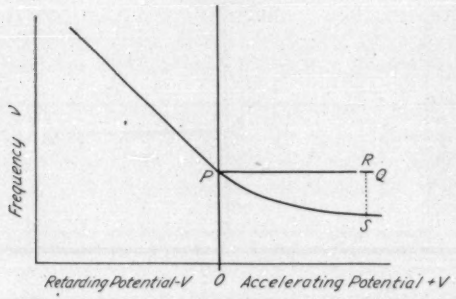
FIG. 36.



to expect any effect at all, as regards the current to the plate B. It is no consolation to the electrons to know that they would receive assistance if they once got out of the metal, if they cannot get out. Thus, if we should formally continue to plot the frequency for zero current against the potential, our curve for what we may call accelerating potentials would become a horizontal line parallel to the potential axis, as in Fig. 36. This is the state of affairs we should expect provided that the external applied field had no effect upon the work function itself. If, however, as a result of the application of the field, the work for electrons to get out of the metal were reduced, then light frequencies which before were too small to succeed in causing the escape of electrons would now be successful; and, for any given accelerating potential we should have to have a lower frequency than that corresponding to the line PQ, in order that

the electrons should just fail to escape. The greater these accelerating fields the greater would be the reduction in the frequency necessary just to secure the departure of electrons from the metal, so that, if we should now plot our curves of frequency against external applied potential, for retarding and accelerating potentials, the curves would take some such form as Fig. 37. As a matter of fact, 300 h/e times the distance RS represents the amount by which the work function W has been reduced by the accelerating field. Now if we seek any theoretical reasons for such a diminution of work function with the accelerating field, we find it difficult to account for a diminu-

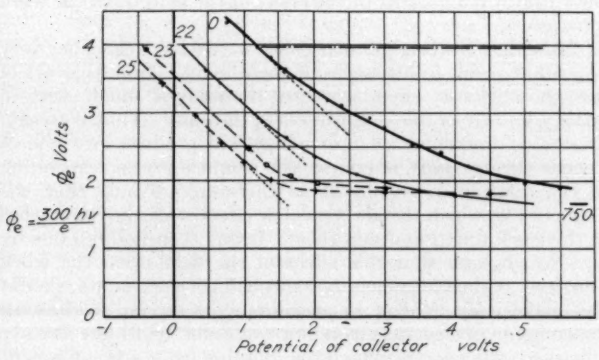
FIG. 37.



tion of appreciable amount. It has been customary to regard the force coming into play during the escape of an electron from a metal as the force exerted by the induced charge on the metal surface. Under these conditions, practically the whole of the region where appreciable attractive forces are exerted on the electron by the plate, is confined to a distance of the order of the one millionth of a centimetre from the metal surface. It is here that the electron pays nearly all of its energy tax to escape. Thus, if the external applied field has to be of any assistance to the electron it must be able to compete with the attractive force on the electron in this region. If one works out the effect of the external field along these lines, he finds that the departure from the straight line PQ which neglects the influence of the external field on the work function, is so

small that it would be quite impossible to represent it in Fig. 37, and make it observable. Only at very high external fields would it become appreciable. Now, Dr. Nottingham's experiments agree entirely with this view for the case of pure metal surfaces. On the other hand, when he coats his surface, in this case a surface of nickel, with a very thin layer of sodium, he finds that the curve obtained by plotting $h\nu/e$ against V, departs from the line PQ by amounts which are quite measur-

FIG. 38.



able even at small external fields. Moreover, both the normal work function and the effect of the field upon it depend upon the thickness of the sodium films. Fig. 38 represents the results for films of different thicknesses, the curve *O* corresponding to the thinnest and the curve marked 25 to the thickest film. While the complete story involves considerations which, while simple, would require too much time to enter upon now, it will suffice to say that these curves contain the data from which we can draw the following conclusions:

(1) The work function diminishes with increase of accelerating field.

(2) The work function for zero field decreases asymptotically with increase of thickness of the film to its value for the metal in bulk.

(3) The significance of the crossing of the curves in Fig. 38 is that, for fields above 10 or 20 volts per centimeter, the work function first diminishes as the thickness of the film increases and then increases with further increase of film thickness to its value for the metal in bulk.

The experimental fact embodied in No. 3 has been known for some time, but it has been customary to attribute it to some intrinsic peculiarity of the effect of thickness upon the constitution of the film, whereas Dr. Nottingham's experiments show that it is an aspect of the effect of the field upon the work function.

Now, Dr. Nottingham has called attention to another very important result following from these facts. Investigators of the photoelectric effect concern themselves much with a quality known as the long wave-length limit. That is to say, the lowest frequency of light which will produce any photoelectric effect. It is, of course, the frequency ν corresponding to the relation $h\nu = W$. It is therefore obvious that the frequency at which the photoelectric effect starts in, diminishes as the work function diminishes. It has been pointed out by Dr. Nottingham that this effect of the field upon the work function, as shown by his photoelectric measurements, should also make itself evident in measurements having to do with the emission of electrons from hot wires; for, as I have already remarked, the current which one obtains from a hot filament depends upon the temperature and upon the work function. One of the classical experiments performed upon this subject concerns the amount of energy which it is necessary to supply to a wire to prevent it from cooling when a thermionic current is drawn from it. The electrons which succeed in escaping from a wire through the surface are those which have an energy sufficient to enable them to overcome the opposition of those forces at the surface which are responsible for what we have called the work function. These are the electrons which are richest in energy, and consequently, as they depart, the metal would become poorer in energy than before, and would cool, were heat not supplied to it to compensate the loss. In the experiment to which I have referred, the procedure was to measure the power which it was necessary to supply to the wire to keep its temperature constant when various thermionic

currents were drawn from it as a result of the action of an electric field applied between the hot wire and the surrounding cylinder. If the work function were independent of the applied field we should expect that, for a given temperature, the energy supplied would be proportional to the electron current drawn away, and would be otherwise independent of the field. Thus we should expect that if we should plot the energy supply per unit current against the field, appropriate corrections being applied for spurious losses and gains of heat, etc., the curve would be a straight line parallel to the field axis. On the other hand, if the work function diminishes with increase of field to a certain limiting value, we should expect that this curve would not be a horizontal line down to the lowest fields, but would diminish from some value higher than that corresponding to this line, asymptotically to the value represented by the line itself. Now, on looking into the data of former investigators on this matter, Dr. Nottingham finds that certain peculiarities in the measurements which at the time seemed unaccountable are just such as would be expected in the light of his investigations upon the photoelectric effect.

The effect of an electric field upon the energy which an electron would have to possess to escape from a metal, presents very interesting theoretical considerations. It could be accounted for if one would assume that, in the absence of the external applied field, there is, natural to the metal itself and to its film, an electric field which extends some distance out from this surface. If one makes this hypothesis, he implies that the work done by the electron in getting out of the metal is extended over a distance comparable with the distance to which this field has an appreciable value, and it is further easy to see that if this distance is appreciable the effect of an external field in altering the work function will be enhanced very greatly over what it would have been on the simple theory that the work done by the electron in escaping was simply that arising from the attraction of the electron for the metal which it leaves. As a matter of fact, it is possible from measurements of the variation of the work function with the field, to deduce the form of this intrinsic surface field if it exists, and Dr. Nottingham has found how the field must vary as we go away from the surface in order to account for the facts.

However, there are logical difficulties in the way of assuming the existence of such a field, difficulties which are not insurmountable, but which suggest the possibility of other avenues of attack. It is possible that the applied field produces some real alteration of distribution of the atoms of the surface film itself, and so alters the work function. It appears that the alteration of the work function produced by the field in the case of thorium films at any rate, exists in certain cases after the field is removed. However, the question of the origin of the alteration of the work function by the field, while of intense theoretical interest, is one which has no bearing upon the definiteness of the experimental results, and of the correlation of the results with those of the photoelectric effect.

ON THE CHANGE OF WAVE-LENGTH OF LIGHT SCATTERED BY A LIQUID.

In 1928 [12] Dr. A. Bramley published the results of certain experiments in which light was passed through a liquid subjected to an alternating electromagnetic field. It appeared that, in the presence of the field, a portion of the light corresponding to certain spectrum lines of the original light suffered a change of wave-length after transmission through the water. The phenomenon presented certain features which were difficult to understand on almost any simple view of the matter. Chief among these was the fact that only certain spectrum lines were affected, while others very near to them in wave-length showed immeasurably small effects. Then the function of the electric field itself was wrapt up in mystery.

Since Dr. Bramley's original publication certain other observers [13] have found the shift in wave-length resulting from passing light through water. However, while Cabannes and Salvaire agree with Dr. Bramley's measurements in finding only a shift of wave-length towards longer wave-lengths, Gross claims shifts in both directions of equal amounts. In neither case do these observers invoke the influence of the

[12] A. Bramley, "Modulation of Light Waves by High Frequency Oscillations," *Nature*, Vol. 122, p. 844, 1928.

[13] J. Cabannes and P. Salvaire, "Elargessement des raies spectrales par diffusion moleculaire," *Comptes Rendus*, Vol. 188. pp. 907–908. E. Gross, "Change of Wave-Length of Light due to Elastic Heat Waves at Scattering in liquids," *Nature*, Vol. 126, pp. 201–202, 1930.

electromagnetic field to produce the results. Cabannes and Salvaire confine their attention to only one spectrum line, while Gross used only two spectrum lines. Thus, these experiments have no bearing upon Dr. Bramley's conclusions as to the difference of the results secured with different lines.

During the preceding year, Dr. Bramley has examined these phenomena in greater detail, and it may be well, at the outset, to state some of the chief conclusions reached. They are as follows:

(1) The conclusion as to the shift of wave-lengths being towards the red, only, was substantiated, in agreement with the former measurements and with the results of Cabannes and Salvaire.

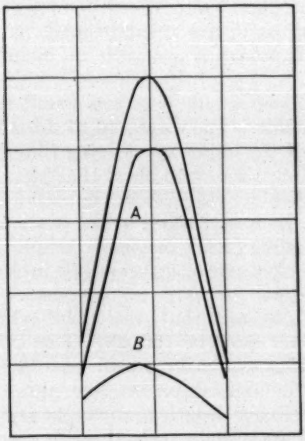
(2) The electromagnetic field was found to have no effect upon the magnitude of the wave-length shift, but it did affect the proportion of the light experiencing that shift.

(3) All the lines examined show the shift; but, owing to a peculiar phenomenon arising from the structure of certain of the lines, the shift was masked in the cases of those lines in the method of observation originally employed. Since this feature presents elements of rather subtle interest, I will speak of it in greater detail.

The indications are that the light which has passed through the water may be thought of as composed of two parts, a part which is unaffected, in wave-length, and which corresponds to the original spectral line, and a part which has suffered a shift in wave-length towards the red. It is possible that the second part is really to be thought of as composed of a number of different parts with different shifts centering around a mean value. For simplicity, let us think of the case of the original line and of a single shifted line. Now owing to phenomena which are reasonably well understood, and concerning which I will not enter into detail here, we know that a spectrum line is not composed of vibrations of absolutely one and only one frequency. If we plot the intensity of the parts of the line against the wave-length, we obtain a curve such as is represented in Fig. 39, *A*, although the curve is not always symmetrical as it is in this case. Since all of the wave-lengths associated with the whole line are so near together, we may with confidence suppose that the corresponding displaced line

B will be obtained from the original line by dividing it into a number of separate parts along the wave-length axis, and then displacing these parts by the same amount, and altering them all in intensity but in the same proportion. This will be true whether the original line is symmetrical or unsymmetrical. When one simply seeks to observe the shift by examining in a spectroscope the light of both kinds transmitted through the

FIG. 39.



water, he observes a combination of the effects of the two curves *A* and *B*, Fig. 39. It is obvious that in certain cases, the displacement of the maximum in the resultant curve will be comparable with the separation of the maxima in the curves *A* and *B*. Such a situation is, in fact represented in Fig. 39. Suppose, however, that curve *A* takes such a form as that shown in Fig. 40. It is then not immediately obvious as to what will be the net result of combining them. Phenomena of this kind have been discussed by Burger and Cittert,[14]

[14] H. C. Burger and P. H. Cittert, "Verbreitering von Spektrallinien durch Selbstabsorption," *Zeit. für Physik*, Vol. 51, pp. 638–651, 1928.

FIG. 40.

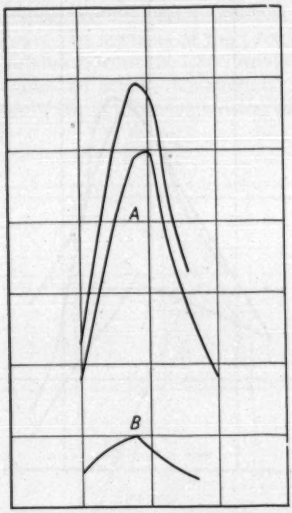


FIG. 41.

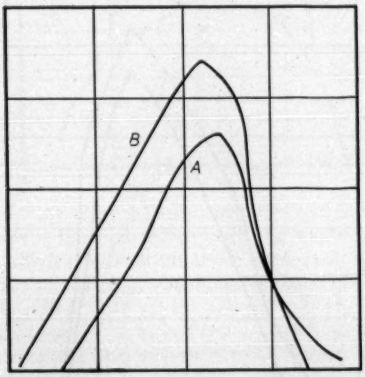


FIG. 42.

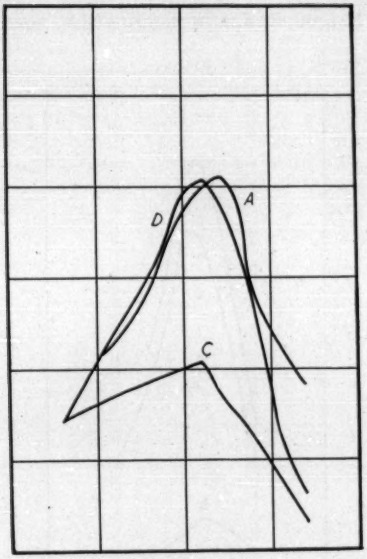
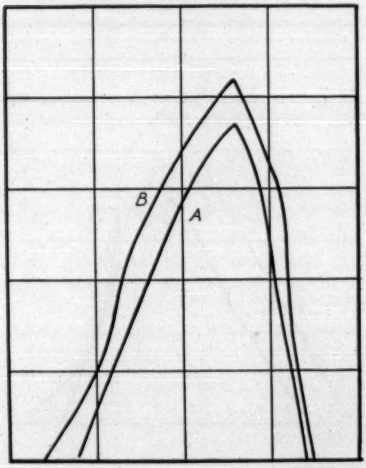


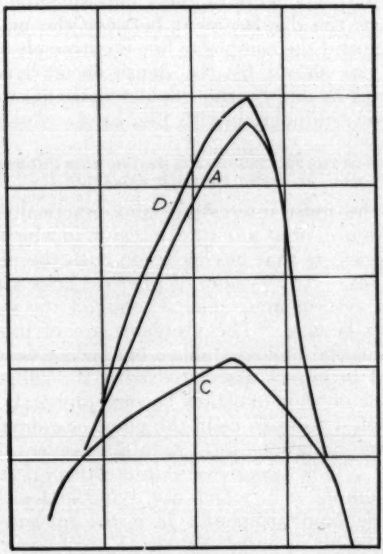
FIG. 43.



who have shown that the wave-length separation of the maxima of two lines may be vastly different from the wave-length separation of the maxima of the principle line and the composite line made up from the two individual lines.

Fig. 41 *A* shows an actual densitometer record of a line for which passage of the light through water gave a measurable

FIG. 44.



shift. Figure 41 *B* is a densitometer record of the line observed after the light passed through the water. Figure 42 *C* is a curve which has been obtained from 41 *A* by altering all the ordinates in the same ratio, and shifting the whole curve to the left. The shift of the curve, and the ratio of the ordinates to those of *A* have been adjusted so as to give, on combination of the two curves, a result shown at *D*, Fig. 42,

as nearly as possible the equivalent of *B*, Fig. 41, and showing the same displacement, of the maxima as is shown by Fig. 41 *A* and *B*, a displacement moreover sensibly the same as that between the maxima of *C* and *A*. For comparison, the curve *A*, Fig. 41 has been shown on Fig. 42.

Figs. 43 and 44 are analogous to Figs. 41 and 42, but are for the case of a line (Fig. 43 *A*) whose densitometer record is different. We see here that, while the displacement between the components of the composite line is the same as in Fig. 41, the displacement between the maxima of the principal line and the composite line is extremely small both in actual fact, as shown by the densitometer records, in the Fig. 43 *A* and *B*, and by the calculated composite curve Fig. 44 *D* taken in conjunction with Fig. 44 *A*.

THE MECHANISM OF THE PROCESS OF CELL DESTRUCTION UNDER BOMBARDMENT BY ALPHA PARTICLE RADIATION.

One of the most interesting, and practically unexplored regions of science, or at any rate, a region in which exploration is in its infancy, is that having to do with the mechanism of vital processes. Any system of physical laws which is to be a consistent system must take account of the way in which living things behave. The problems are of interest to the physicist, and the biologist alike; but, when we come to the fundamental processes associated with the subject, the language and the method of attack become physical. Life manifests its simplest form to us in the plant or animal cells. We know that the radiations from radium possesses the power to destroy cells. This raises several interesting questions. Consider, for example, cells which are dying under the action of alpha particle bombardment. Is it the nucleus of the cell which must be hit in order that death shall occur, and is one hit by a single alpha particle sufficient to kill the cell, or must there be several hits? Does the first hit simply make the cell sick, and the second one knock it out? Then again, suppose, for example, that the essential thing to be hit in the cell, is one of the chromosomes, and suppose the total volume of the chromosomes in all of the cells which we happen to be viewing with the microscope is a millionth of a cubic centimeter. Suppose that the intensity of our alpha radiation is such that

any particular millionth of a cubic centimeter is struck by an alpha particle on the average once a minute, then if it is the chromosome which is the vital spot, we should expect one cell per minute to die in the field of view. You can easily see that by experiments of this kind, we could gain information as to the size of the entity in the cell which has to be bombarded in order that death shall occur. Then again, we might have interesting phenomena of the following kind. Suppose that we should dissolve radium emanation in the liquid in which the cell is mounted. The range of an alpha particle is only of the order of 5 centimeters in air, and in substance like water its range is only of the order of one half of a tenth of a millimeter. If now, we should have a cell in which the nucleus was at the center, and whose radius was greater than one half of a tenth of a millimeter, an alpha particle would never be able to reach its center, so that if the nucleus is the vital spot where bombardment causes death, such a cell would never die under the bombardment of alpha particles, unless the radium emanation can pass through the cell wall and dissolve in the protoplasm. It is with the object of settling such questions as the foregoing that Mr. del Rosario has undertaken a series of experiments. He has used cells of euglena, so far, because these cells maintain a violent agitation when they are alive, and it is consequently easy to observe when they die.

The procedure was to place the cells in a specially prepared shallow dish suitable for observation under a microscope, and capped with a thin microcoverslip. The radium emanation was introduced in a sealed tube which could be inserted in a hole in the side of the container and broken at the appropriate time so as to allow the emanation to escape and some of it to dissolve in the liquid. The number of living cells in the field of view was then counted at intervals of about ten minutes for a period of the order of magnitude of one hour. Each count itself took about three minutes. The experiment was carried out for various strengths of radium emanation; and, in each case, the strength of the emanation tube was obtained by comparison of the rate of deflection produced by it and by a radium standard when placed at a fixed distance from a charged electroscope. The amount of emanation going into solution was of course obtained by calculation.

All counting experiments of the above kind were accompanied by control experiments with a specimen in which no radium emanation was inserted. These control experiments were then used to correct the main observations for such phenomena as natural cell division, etc.

Elements of the Theory of the Process.—It is easy to show that the total number of α particles entering a surface S per cent. in the liquid is

$$N = \frac{RqS}{4} \qquad (1),$$

where q is the rate of emission of α particles per c.c. of the liquid, and R is the distance which an α particle can travel in the liquid.

Case 1.—The simplest hypothesis is to the effect that there is in the cell some sensitive region of surface area S, such that if an α particle enters this region death occurs. It is easy to show that, under this assumption, the number n_t of living cells at a time t after the introduction of the emanation is

$$n_t = \bar{n}e^{-Nt} \qquad (2),$$

where N has the value given in equation (1).

The characteristic features of this case as shown by (2) are:

A linear relation between $\log n_t$ and t with the slope of the curve equal to $-N$; or, in other words,

$-(1/n)(dn/dt) = N$, and is therefore a constant, i.e., it is independent of the time.

The value of N determined as above serves through (1) to give the area of the sensitive surface S, and so the mean radius, defined as the radius of a sphere having the same area as S.

Case 2.—In case we desire to consider a situation where two impacts of an α particle with the sensitive element of the cell are necessary to cause death the situation becomes more complicated. Moreover, we ought, for generality, to admit the possibility of a cell recovering after the first impact, and before the second, so that the effect of the first impact is lost. When we take account of all these considerations, we have to consider several states which we shall designate as states 0, 1, 2, as follows:

State 0 refers to a cell which has suffered no collision with α particles, or which has recovered from a collision suffered.
State 1 refers to a cell which has suffered one collision, and has not recovered.
State 2 refers to a cell which has suffered two collisions without recovery between, and is consequently dead.
Let $\bar{n}$ be the number of live euglena cells per c.c. at $t = 0$, and let n_0, n_1, and n_2 be the numbers per c.c. in states zero, one and two respectively, at any subsequent time t.

It is then easy to show that the equations which control the progress of the phenomena are

$$\frac{dn_0}{dt} = -Nn_0 + \lambda n_1, \tag{3}$$

$$\frac{dn_1}{dt} = -\frac{dn_0}{dt} - Nn_1, \tag{4}$$

$$\frac{dn_2}{dt} = Nn_1, \tag{5}$$

where λ is such a constant that λn represents the number in the state 1 which recover per second

It is then a matter of straight-forward mathematics to show that if $n_l (= n_0 + n_1)$ is the number per c.c. alive at any instant,

$$\frac{1}{n_l}\frac{dn_l}{dt} = -\frac{(\alpha^2 - \beta^2)(e^{2\beta t} - 1)}{(\alpha + \beta)e^{2\beta t} - (\alpha - \beta)}, \tag{6}$$

where

$$\alpha = N + \frac{\lambda}{2}; \qquad \beta = \left(N\lambda + \frac{\lambda^2}{4}\right)^{1/2} \tag{7}.$$

Quite apart from this solution, we can see directly from (5) that, for the case where two α particle impacts are necessary to kill the cell, $dn_2/dt = 0$ at $t = 0$, since $n_1 = 0$ at $t = 0$. Hence, since $n_l = \bar{n} - n_2$, we have

$$\frac{1}{n_l}\frac{dn_l}{dt} = 0,$$

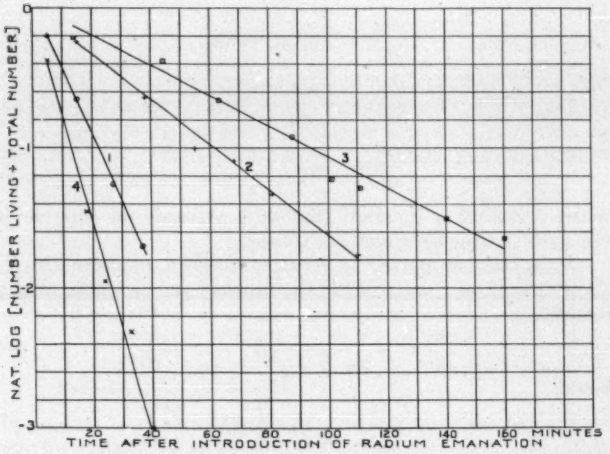
at $t = 0$. For Case 1, $(1/n_l)(dn_l/dt) = -N$ for all time, so that we have here a method of distinguishing between cases (1) and (2).

Results.—The results of Mr. del Rosario's experiment are shown in Fig. 45, in which the ordinates represent the values of $n_t/\bar{n}$ and the abscissæ are the times. It will be seen that the relation is a linear one, so that

$$\frac{d}{dt}\left(\log \frac{n_t}{\bar{n}}\right) = \frac{1}{n_t}\frac{dn_t}{dt} = \text{constant},$$

the constant being, in fact, $-N$ in accordance with the theory applicable to case 1.

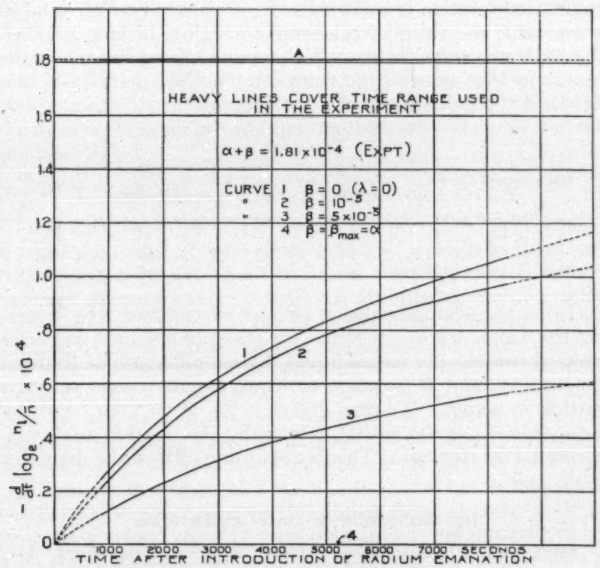
FIG. 45.



Of course, one might conceivably suppose that since Mr. del Rosario's results did not extend right up to $t = 0$, it might happen that the curves, if plotted accurately up to that limit, would finally show a bend near the limit in such a manner as to be consistent with a zero value for $(1/n_t)(dn_t/dt)$ there, and that all the peculiarities of the curve would lie near to $t = 0$, leaving only the simple linear relation found by Mr. del Rosario for the larger values of t. Such a situation is very unlikely; but, in order to rule it out entirely, we may proceed

as follows: At $t = \infty$ equation (6) leads to the result $(1/n_1)(dn_1/dt) = -(\alpha + \beta)$ so that even if the slopes of the curves in Fig. 45 had not been constants for lower values they would approach finite and constant values for larger values of t, and the slopes would give the value of $-(\alpha + \beta)$. The experiments thus give the proper value for $(\alpha + \beta)$, inde-

FIG. 46.



pendently of uncertainty of the measurements near $t = 0$. If then for a fixed value of $(\alpha + \beta)$ we draw the curves for the totality of values of β, this singly infinite set of curves will comprise all of the doubly infinite set of curves which could be obtained by assigning all values to N and λ, and which would also be consistent with the experiments. Figure 46 shows, for one case (that corresponding to the curve 3 of Fig. 45), the set

of curves corresponding to the value of $(\alpha + \beta)$ for that case and for all values of β. The experimental curve is shown by A. It will be seen that since curve 1, Fig. 46 is a limiting curve of the set, no choice of β can make the theoretical curves fit the experimental curve, so that we fall back upon Case 1 as the one which fits the parts.

From (1) it is obvious that N/q should be constant, and consequently, since q is proportional to I, the content of the emanation solution in millicuries, we should have N/I equal to a constant, the value of this constant being, in fact, $qRS/4I$. Table IV gives the values of N/I corresponding to each of the curves in Fig. 45, and the constancy of this quantity is evidence of the harmony of the experiments.

TABLE IV.

Minus Slope of Curve N.	Strength of Ra. Em. Millicuries I.	$\frac{N}{I} = \frac{q}{I}\frac{RS}{4}$.
7.9×10^{-4} sec.$^{-1}$	1.35	5.91
2.74×10^{-4} sec.$^{-1}$	0.51	5.36
1.81×10^{-4} sec.$^{-1}$	0.30	6.03
12.5×10^{-4} sec.$^{-1}$	1.97	6.34

From the average value of $qRS/4I$ we can find S by inserting the value $q/I = 8.7 \times 10^5$ for the number of α particles emitted per sec. per c.c. of liquid by one millicurie of Radium Emanation and $R = 3.6 \times 10^{-3}$ cm. for the range of an α particle in water. We thus find $S = 7.5 \times 10^{-7}$ cm.^{2} and the mean values ϵ of the entity, defined by the relation $4\pi\epsilon^2 = S$, is $\epsilon = 2.4 \times 10^{-4}$ cm. This is about one fifth of the diameter of the cell.

THE PRODUCTION OF X-RAYS BY PROTONS.

Last year, I described certain experiments which Dr. Barton was performing with the object of testing the efficiency of production of X-rays by bombardment of a target, not with electrons, but with protons. A proton has a mass about 1800 times as great as that of the electron, so that the conditions for the production of X-rays are entirely different, and a knowledge of the efficiency of X-ray production by electrons, provides a valuable criterion in terms of which to judge the merits of any theory proposed for X-ray production in general.

I will not describe this interesting experiment in any detail, since I described it last year. Since, moreover, the results have been published in the Journal of the Institute,[15] it will suffice to say that Dr. Barton found that the number of X-rays produced by a beam of protons is less than the one hundred thousandths part of the number of X-rays produced by a beam containing an equal number of electrons of the same energy. It is of interest to recall that the ratio of the mass of the proton to the electron is about 1800. The three halves power of this ratio is about 80,000, and the square of the ratio is about 3,000,000, so that any theory which attempts to account for the production of X-rays in the light of these experiments, must predict an efficiency which varies inversely with the mass to a higher power than the three halves, for a constant energy.

EXPERIMENTS ON ABSORPTION OF COSMIC RAYS.

Another experiment on which I reported in preliminary manner last year is one referring to the measurement of the cosmic radiation, at three altitudes, Pike's Peak, Colorado Springs, and sea level. It will not go into any details, since the complete account of the work has been published in the Journal of the institute,[16] and it will be sufficient to remark on the main conclusions. As you will recall, it has become customary to think of the cosmic rays as of the nature of very hard X-rays, and it is a matter of interest to inquire as to the various frequencies which go to make up the cosmic rays which we observe. We have been accustomed to think of each particular wave-length of the cosmic radiation as having a definite coefficient of absorption in the atmosphere, characteristic of that wave-length, so that measurements at different altitudes give some information as to the different coefficients of absorption involved in the composite system of cosmic rays. An analysis of the data showed that it was possible to account

[15] H. A. Barton, "Comparison of Protons and Electrons in the Excitation of X-rays by Impact," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 209, pp. 1–19, 1930.

[16] W. F. G. Swann, "The Variation of the Residual Ionization with Pressure at Different Altitudes, and its Relation to the Cosmic Radiation," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 209, pp. 151–200, 1930.

TABLE V.

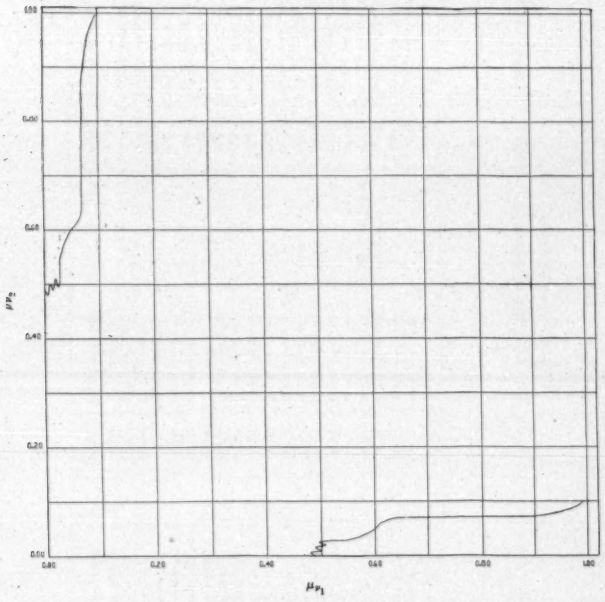
μ_{P_2} = 0.01.		μ_{P_2} = 0.05.		μ_{P_2} = 0.08.		
μ_{P_1}.	μ_{P_2}.	μ_{P_1}.	μ_{P_2}.	μ_{P_1}.	μ_{P_2}.	
0.02	0.50 → 0.51	0.02	0.51 → 0.60	0.02	0.51 → 0.94	
0.04	0.50 → 0.58	0.04	0.58 → 0.60	0.04	0.58 → 0.94	
0.06	0.50 → 0.61	0.06	0.61 → 0.60	0.06	0.61 → 0.94	
0.08	0.50 → 0.94	0.08	0.94 → 0.60	0.08	***	
0.10	0.50 → (> 0.98 < ∞)	0.10	(> 0.98 < ∞) → 0.60	0.10	(> 0.98 < ∞) → 0.94	
0.15	0.50 → ∞	0.15	∞ → 0.60	0.15	∞ → 0.94	
0.20	0.50 → ∞	0.20	∞ → 0.60	0.20	∞ → 0.94	
0.25	0.50 → ∞	0.25	∞ → 0.60	0.25	∞ → 0.94	
0.30	0.50 → ∞	0.30	∞ → 0.60	0.30	∞ → 0.94	
0.35	0.50 → ∞	0.35	∞ → 0.60	0.35	∞ → 0.94	
0.40	0.50 → ∞	0.40	∞ → 0.60	0.40	∞ → 0.94	
0.45	0.50 → ∞	0.45	∞ → 0.60	0.45	∞ → 0.94	
0.50	**	0.50	∞ → 0.60	0.50	∞ → 0.94	0.00 → 0.01
0.55	0.50 → 0.003	0.55	∞ → 0.60	0.55	∞ → 0.94	0.00 → 0.03
0.60	0.50 → 0.05	0.60	**	0.60	∞ → 0.94	0.00 → 0.05
0.65	0.50 → 0.07	0.65	0.07 → 0.60	0.65	∞ → 0.94	0.00 → 0.07
0.70	0.50 → 0.07	0.70	0.07 → 0.60	0.70	∞ → 0.94	0.00 → 0.07
0.75	0.50 → 0.07	0.75	0.07 → 0.60	0.75	∞ → 0.94	0.00 → 0.07
0.80	0.50 → 0.07	0.80	0.07 → 0.60	0.80	∞ → 0.94	0.00 → 0.07
0.85	0.50 → 0.07	0.85	0.07 → 0.60	0.85	∞ → 0.94	0.00 → 0.07
0.90	0.50 → 0.074	0.90	0.074 → 0.60	0.90	∞ → 0.94	0.00 → 0.074
0.95	0.50 → 0.082	0.95	0.082 → 0.60	0.95	0.082 → 0.94	

TABLE V.—*Continued.*

μ_{P_3} = 0.135→ 0.48.		μ_{P_3} = 0.060.		μ_{P_3} = 0.90.	
μ_{P_1}.	μ_{P_2}.	μ_{P_1}.	μ_{P_2}.	μ_{P_1}.	μ_{P_2}.
0.02	0.51 → ∞	0.02	0.05 → 0.51	0.02	0.074 → 0.51
0.04	0.58 → ∞	0.04	0.05 → 0.58	0.04	0.074 → 0.58
0.06	0.61 → ∞	0.06	0.05 → 0.00	0.06	0.074 → 0.61
0.08	0.94 → ∞	0.08	0.05 → 0.00 0.94→∞	0.08	0.074 → 0.00 0.94 → ∞
0.10	> 0.98 < ∞ → ∞	0.10	0.05 → 0.00 (>0.98 < ∞)→∞	0.10	0.074 → 0.00 (> 0.98 < ∞)→∞
0.15	*	0.15	0.05 → 0.00	0.15	0.074 → 0.00
0.20	*	0.20	0.05 → 0.00	0.20	0.074 → 0.00
0.25	*	0.25	0.05 → 0.00	0.25	0.074 → 0.00
0.30	*	0.30	0.05 → 0.00	0.30	0.074 → 0.00
0.35	*	0.35	0.05 → 0.00	0.35	0.074 → 0.00
0.40	*	0.40	0.05 → 0.00	0.40	0.074 → 0.00
0.45	*	0.45	0.05 → 0.00	0.45	0.074 → 0.00
0.50	0.00 → 0.025	0.50	0.05 → 0.01	0.50	0.074 → 0.01
0.55	0.00 → 0.03	0.55	0.05 → 0.03	0.55	0.074 → 0.03
0.60	0.00 → 0.05	0.60	***	0.60	0.074 → 0.05
0.65	0.00 → 0.07	0.65	0.05 → 0.07	0.65	0.074 → 0.07
0.70	0.00 → 0.07	0.70	0.05 → 0.07	0.70	0.074 → 0.07
0.75	0.00 → 0.07	0.75	0.05 → 0.07	0.75	0.074 → 0.07
0.80	0.00 → 0.07	0.80	0.05 → 0.07	0.80	0.075 → 0.07
0.85	00.0 → 0.07	0.85	0.05 → 0.07	0.85	0.074 → 0.07
0.90	0.00 → 0.074	0.90	0.05 → 0.074	0.90	***
0.95	0.00 → 0.082	0.95	0.05 → 0.082	0.95	0.074 → 0.082

for the three sets of observations by assumption of two coefficients of absorption, and to do this in various ways. Fig. 47 shows corresponding pairs of absorption coefficients μ_{P_2} and μ_{P_1} which may be chosen to fit the data for the three altitudes. Thus, for example, it is possible to account for the

FIG. 47.



results with one absorption coefficient 0.60, and the other absorption coefficient 0.05. It is also possible to account for them with an absorption coefficient 0.99, and another 0.10. On the other hand, if we decide to admit three absorption coefficients, we have a very wide range of possibilities. The results are represented in Table V.

Its significance may be illustrated by taking an example. Suppose we decide upon one absorption coefficient 0.01, and another 0 06. Then the third may have any value between 0.50 and 0.61; and, out of the three chosen absorption coefficients it will be possible by assignment of suitable amounts of the radiation with those absorption coefficients to explain the experimental results. Then if one tries, for example, 0.05 for one, and 0.20 for another, we can choose the third having any value between infinity and 0.60 to account for the experimental results. These particular data do not have any very fascinating popular appeal, but they do constitute facts of significance to those who are interested in drawing conclusions as to the nature of the radiation necessary to account for observed experimental facts from observations at a limited number of altitudes.

INVESTIGATIONS OF LONG HEAT RAYS.

One of the most curious facts which strikes anyone who makes a survey of physics for the first time is the apparent contrast between the way in which things happen in things of gross size, and the way in which they happen in the atom. In the large scale phenomena, everything seems to go on according to well recognized laws, and in a fashion simple and understandable, whereas, in the atomic kingdom things seem to go on in a fantastic manner. Energy is emitted in little chunks instead of continuously; our old law of force between particles no longer serves to describe the motions which we observe. Everything seems curious and artificial. Of course, it is not surprising that the coarse-grained phenomena seem to go on in simple fashion, because our laws of physics were constructed originally to harmonize with such phenomena. The scaffolding of our thoughts had conformed to the frame of nature, so as to fit the grosser lines of its structure at a time before the fine architecture of that structure had revealed itself. The older scaffolding had made but little provision for this fine structure, which fitted, therefore, badly into it, and demanded a scaffolding of its own, a scaffolding which could be patched onto the older one only with difficulty. Speaking rather generally, one may say that in small structures which are of a size such that they could be made by the hands of man, things go on according to the old simple theories of fifty years ago.

But for all structures such as atoms and molecules beyond the power of man to fashion, they go on according to the more mysterious laws of the quantum theory. Confining our attention for the moment to those phenomena which involve the radiation of light, or electromagnetic waves, we may say that, if the wave-length of the radiation is such as could be produced by a mechanically made apparatus, the phenomena go on according to classical theories, whereas if the structure necessary to produce it is of atomic dimensions, then it is the quantum theory which is applicable. Of course, the quantum theory has provided for a consistent merging of itself and classical theory. Nevertheless, it would be an interesting thing if one could take something which was of dimensions comparable with those which man can construct, and actually see it behaving as an atom behaves. Now such a situation seems just within the reach of practicability, and we are at present persuing investigations along these lines. Let me cite one or two experiments which we are carrying out to test some of these matters. Let us concentrate our attention for a moment upon the waves emitted by a hot body of the order of one hundredth of a millimeter in length, and upon a band of those waves corresponding to a range of about one thousandth of a centimeter in wave-length. Now we have been accustomed to think of the mechanism of absorption of radiation by a body through which the radiation passes, as arising from little oscillators of some kind, which are set into vibration by the radiation and abstract energy from it. In particular, in considering this matter mathematically, it has been customary to adopt a rather abstract point of view. We consider a box of material which acts as the absorber, and we consider that little box as a whole as regards the motions within it. If we take a string and twang it in the middle, it will vibrate as one piece. If we constrain the midpoint to remain at rest, it will vibrate in two halves. If we constrain a point one-third of the way along to remain at rest, it will vibrate in thirds, and so on. We know that it is possible to represent any irregular motion of the string by a suitable combination of motions of these simple types. And so it is possible to represent any complicated electromagnetic disturbance in our box as something made up of simple oscillations having definite relations to the

dimensions of the box. It has been customary to associate each of these oscillations with an independent oscillator which can respond to the frequency of vibration transmitted through the medium. These are the oscillators which absorb the the energy from the oncoming wave. It is also these oscillators which are responsible for the emission of heat from the body when it is radiating. It is a characteristic feature of the absorption of radiation that oscillators which are mainly responsible for the absorption of radiation of any given frequency are those oscillators which themselves have a frequency almost equal to that particular frequency. It is also easy to see that the wave-length corresponding to the lowest frequency in a situation of this kind is comparable with the dimensions of the box. Suppose now we should send upon this box radiation which is composed of wave-lengths which are for the most part smaller than the dimensions of the box. Then, we shall always be able to find oscillators which are in a position to respond to that radiation and so cause absorption of it. On the other hand, if we should send onto the box radiation of a wave-length longer than its dimensions, the box would have no oscillators which would be capable of responding to the radiation, and the radiation would fail to be absorbed. It is only for the purpose of mathematical simplicity in speaking about the problem, that we confine our attention to a rectangular box of this kind. We may say, in general, that if a particle has any given dimensions, then it may be expected to fail to absorb radiation of a wave-length longer than those dimensions. Thus, if we should imbed in an insulator a lot of metal particles of dimensions of the order of one hundredth of a millimeter and should direct upon them radiation of successively increasing wave-lengths, diminution of the power of the medium to absorb should be observed when a wave-length of the order 0.01 mm. was passed. In such a case we should have a result following from the co¨peration of a thing of almost man made dimension, of the small particle, and a wave motion produced not with a radio apparatus of man made construction, but one produced by the subtle performances of atomic systems. Again, at sufficiently low temperatures, the oscillations which are concerned in heat motions are preponderantly of wave-length sufficiently large to be comparable with the

diameters of small wires which can actually be produced. If then, for various temperatures of the surroundings, we should measure the rate at which heat is radiated from such wires when raised a fixed amount above the temperature of the surroundings, we should find a sharp change in the radiation as the temperature of the surroundings passed through that region for which the wave-lengths for maximum energy radiation became comparable with the diameter of the wires. Again, a careful investigation of the law of the variation of heat radiation with wave-length and temperature at low temperatures should be of particular interest, because from such data we have a means of ascertaining whether oscillators of relatively large size are behaving according to the simple theory of days gone by, or are participating in what would be, for them, the extraordinary phenomena of experiencing "quantum jumps" in energy.

It is by a series of investigations of the foregoing kind that we are endeavoring to seek as much light as possible upon the manner in which the phenomena of the large scale things of life and those of the atom merge into each other.

MISCELLANEOUS THEORETICAL INVESTIGATIONS.

Finally, I must do no more than refer to one or two investigations of the form of a critical survey of certain broad features of modern electrodynamics and atomic theory. These are of a nature which it is impossible adequately to summarize in a report of this kind, and I must refer those interested to the complete publications on the subject.[17]

[17] Since this Report was presented, these investigations have been published in full, under the following titles: "Relativity and Electrodynamics," by W. F. G. Swann, *Review of Modern Physics*, July, 1930. "Contemporary Theories of Light," by W. F. G. Swann, *Journal of the Optical Society*, Vol. 20, No. 9, September, 1930.

MEASUREMENT OF POLARIZATION OF THE TYNDALL BEAM OF AQUEOUS SUSPENSIONS AS AN AID IN DETERMINING PARTICLE SIZE.

BY

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INTRODUCTION.

The particle size of a non-uniform particulate substance is best determined by direct microscopic measurement of the individual particles in a representative sample of the material. This is time-consuming work, however, and is frequently replaced by a more rapid indirect method. In general, the indirect methods are based upon easily determined measurements that are functions of particle size. Some methods give quantitative results whereas others are simply relative unless calibration data are available.

An easily measured function of particle size is the strength of the Tyndall beam created by suspension of finely divided materials. The effect of particle size upon the Tyndall reading of suspensions of known concentration has been studied by the authors and reported in a recent paper (1).

It has been observed that particle size influences not only the strength of the Tyndall beam but affects the character of the light making up the beam as well. Thus, characteristic colors have been observed in beams created by materials of different sizes. It has also been observed that the light is partially polarized and that the degree of polarization depends upon particle size and concentration of the suspension as well as upon optical properties of the material. So far as the authors know, however, the relationship has not been expressed in mathematical form.[1] This phenomenon may be considered as a possible aid in the study of size characteristics of non-uniform particulate substances. An investigation of this

[1] The polarization of light in the Tyndall beam created by suspensions of finely divided materials has been investigated in a study of the characteristics of metal oxide clouds (2).

relationship was therefore undertaken. The materials examined ranged in size from one to fifty microns. The results, reported in the present paper, indicate that the degree of polarization is a function of the arithmetic mean diameter of the suspended material.

EXPERIMENTAL.

The experimental approach to the problem was based upon the following established observations:

(*a*) Maximum polarization of light scattered by suspensions of fine particles occurs at right angles to the incident beam.

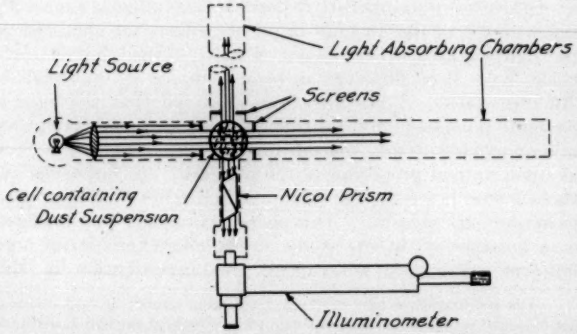
(*b*) The plane of polarization is parallel to the incident beam.

(*c*) The degree of polarization varies with

1. Optical properties of the material, particularly the index of birefringence.
2. Particle size.
3. Concentration of suspension.

Three materials were selected: quartz (99.7 per cent. SiO_2), ground crystals of calcite (Iceland Spar) and granite dust obtained from the bag filters of a stone-cutting shed. These materials were available in a wide range of sizes. The

FIG. 1.



Diagrammatic sketch of modified Tyndall meter, showing position of Nicol Prism.

mathematical treatment of the size properties of the samples studied has been given in a previous paper (1).

Water suspensions were prepared from these materials and examined in the Tyndall meter (3). Suspensions were prepared in unknown concentrations of such strength as to give Tyndall readings close to the upper limit of the illuminometer.

The Tyndall meter was modified, as shown in Fig. 1, in order to determine the degree of polarization of the Tyndall beam. A Nicol prism was placed in the light path between the dust cell and the illuminometer and mounted so that it could be rotated about its optical axis. Thus, two readings were obtained; the first gave the strength of the full-light beam and the second, the strength of that portion of the beam which was composed entirely of non-polarized light. The second reading was obtained after the polarized light had been screened out by turning the prism 90° from the position of maximum reading.

The concentration of each of the suspensions was gradually reduced by dilution and for each dilution Tyndall readings for both full-light[2] and non-polarized light were obtained. Twelve samples, ranging in size from one to fifty microns, were examined in this manner.

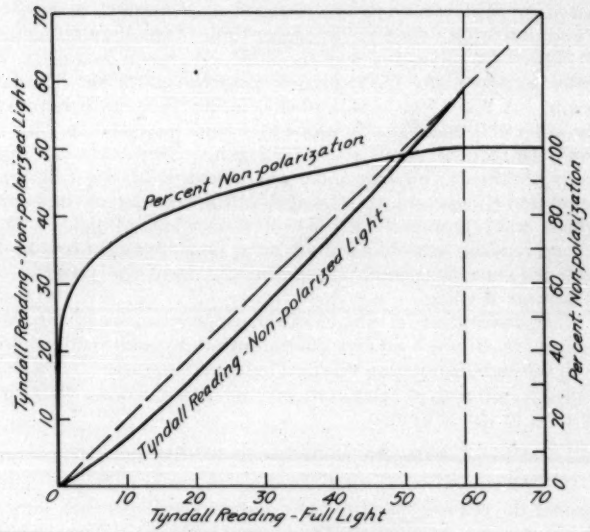
DATA AND DISCUSSION OF RESULTS.

By plotting the Tyndall readings for non-polarized light against the readings for full light, curves similar to that shown in Fig. 2 were obtained for the various samples. The dashed line at 45° indicates the relationship that would exist if none of the light were polarized. The vertical difference between this line and the curve, therefore, represents the amount of polarized light at any concentration (represented by the full-light reading). It will be observed that the curve meets the 45° line at a definite concentration. Whether this is true or whether the curve becomes asymptotic cannot be definitely stated at this time. It can be said, however, that the degree of polarization varies with concentration, approaching complete polarization at low concentrations and complete non-

[2] It should be noted that the Nicol prism cut out a certain amount of light so that the full-light readings reported are considerably less than the readings for equal concentrations given in our previous paper.

polarization as the concentration increases. This is indicated by the curve in Fig. 2 showing per cent. non-polarization.

FIG. 2.



Typical curves, showing variation of polarized light in the Tyndall beam with concentration of suspension.

The Tyndall reading, for non-polarized light, bears an exponential relation to the reading for full light. The equation of the curve has the general form:

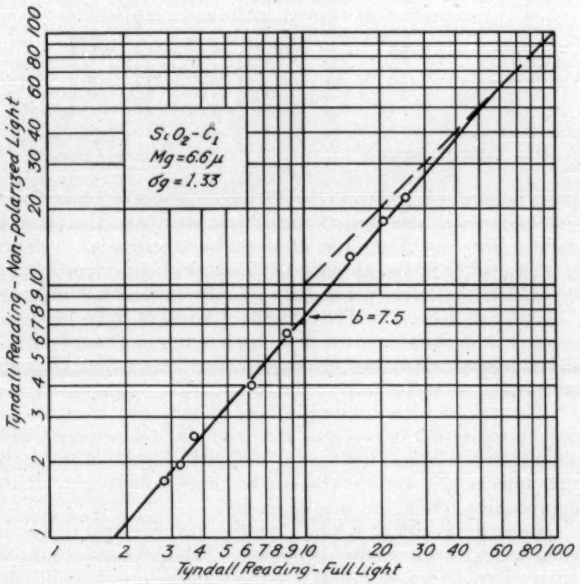
$$y = ax^n$$

and therefore plots as a straight line on double-logarithmic paper. Readings for a particular sample, SiO_2-C_1, are shown plotted on double-logarithmic paper in Fig. 3. Similar curves were prepared for the other samples. Straight lines of best fit were drawn in by eye and in the main excellent correlations were obtained.

The values of a and n were found to vary in the same

manner with particle size. The accuracy of these parameters, however, depends upon the care with which the lines are fitted and they were therefore discarded in favor of a single parameter of the curve—the value of the Tyndall reading given by non-polarized light when the full light reading had a value of ten. This single parameter, b, depends upon both a and n but

FIG. 3.


Tyndall Reading - Non-polarized Light
1 2 3 4 5 6 7 8 9 10 20 30 40 60 80 100
Tyndall Reading - Full Light
1 2 3 4 5 6 7 8 9 10 20 30 40 60 80 100
Si O2 - C1
Mg = 6.6 μ
σg = 1.33
b = 7.5

Relation between non-polarized light and full-light Tyndall meter readings for sample SiO_2-C_2, plotted on double-logarithmic paper.

is subject to less variation due to errors in curve fitting. The value of b for sample SiO_2-C_1 is indicated in Fig. 3 and its value for the various samples studied is tabulated in Table I.

Influence of Particle Size upon Parameter b.—We now have to consider the effect of particle size upon the value of b. It

TABLE I.

*Size Characteristics * and Values of b for Twelve Finely Divided Samples of Silica, Granite Dust, and Calcite.*

Sample.	M_g.	σ_g.	δ.	Δ.	D.	D^2/Δ^2.	b.
Silica-E	1.73	1.42	1.84	1.95	2.07	2.35	5.8
" 6	1.85	1.77	2.18	2.57	3.02	4.20	5.95
" D	4.4	1.34	4.59	4.79	5.00	5.43	7.0
" 5	4.6	1.63	5.2	5.85	6.60	8.37	7.1
" C_1	6.6	1.33	6.86	7.15	7.43	8.06	7.5
" A	9.2	2.00	11.72	14.9	18.95	30.80	8.1
" A_2	12.0	1.80	14.29	16.9	20.15	28.5	8.1
" B_1	14.5	1.40	15.31	16.2	17.2	19.2	8.3
Granite-12	1.45	1.69	1.66	1.91	2.19	2.90	5.53
Calcite-14	47.0	1.32	48.9	50.2	52.7	56.9	8.5
" 17	6.1	1.60	6.81	7.60	8.49	10.6	7.7
" 18	1.15	1.35	1.20	1.26	1.31	1.44	6.6

* See Table III, page 799.

must be remembered that the various samples examined were not uniform in size and that particle size may therefore be defined in terms of any one of several diameters (4). Hence, it is necessary in the absence of theoretical considerations, to determine the relationship between the parameter and each "average diameter." The various diameters have been calculated from the size frequency characteristics of each sample in the manner described in our previous paper (loc. cit.) and are presented in Table I.

The value of b is limited in both directions. For 100 per cent. polarization it becomes zero and for 100 per cent. non-polarization it equals ten. It varies with the size of the material, approaching zero as the size becomes infinitely small and approaching ten as the size increases.

Since the parameter b has an upper finite limit of ten its variation with size cannot be linear. For purposes of graphic analysis, therefore, it is desirable to choose a function of b such that its variation with size is a straight line. This characteristic, it was found, is given by the function

$$f(b) = \log\left(\frac{b}{10 - b}\right),$$

when plotted against the logarithms of particle size. Following this scheme of plotting, the relationship was found

to be linear for each of the "average diameters," but the correlation was highest in the case of the arithmetic mean. This is indicated by the fact that the average deviation of observed values of $(b/10 - b)$ from the curve was smallest for this diameter. The average deviations for the five diameters are given in Table II.

TABLE II.

Per cent. Average Deviations of Observed Values of $(b/10 - b)$ from the Fitted Line when Correlated with Various "Average Diameters" on Double-Logarithmic Paper.

Aver. Diameter.	Symbol.	Per cent. Aver. Deviation.
Geometric Mean	Mg	2.64
Arithmetic Mean	δ	2.07
Mean Surface Area	Δ	4.37
Mean Volume	D	8.14
Mean Specific Surface	D^3/Δ^2	10.88

It will be observed, however, that the percentage deviation is small in the case of the Geometric Mean and Mean Surface Area diameters as well as the Arithmetic Mean. An additional analysis is therefore desirable before definite conclusions can be drawn concerning the exact nature of variation in b with particle size.

The five average diameters have been defined by the authors (loc. cit.) in terms of the statistical parameters of the size frequency curves, as given in the following, Table III.

TABLE III.

Average Diameters of Non-Uniform Particulate Substances in Terms of the Parameters of their Size-Frequency Curves.

Aver. Diameter.	Symbol.	Equation.
Geometric Mean	Mg	50 per cent. size.
Arithmetic Mean	δ	$\log \delta = \log Mg + 1.1513 \log^2 \sigma_g$.
Mean Surface Area	Δ	$\log \Delta = \log Mg + 2.3026 \log^2 \sigma_g$.
Mean Volume	D	$\log D = \log Mg + 3.4539 \log^2 \sigma_g$.
Mean Specific Surface	D^3/Δ^2	$\log D^3/\Delta^2 = \log Mg + 5.7565 \log^2 \sigma_g$.

It will be observed that size can be expressed by the general equation

$$\log S = \log M_g + f \log^2 \sigma_g,$$

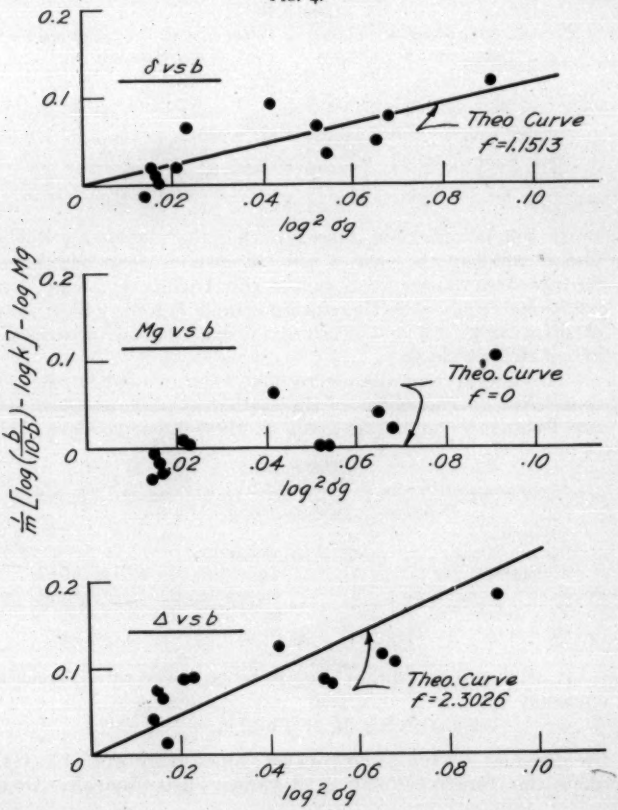
the constant f having the various values given in Table III. Since the function $(b/10 - b)$ varies logarithmically with

size, we may write

$$\log\left(\frac{b}{10-b}\right) = \log k + m \log S.$$

Substituting the general expression for size in this equation,

FIG. 4.



Relation between the average diameters, Mg, σ and Δ and the parameter b.

we obtain

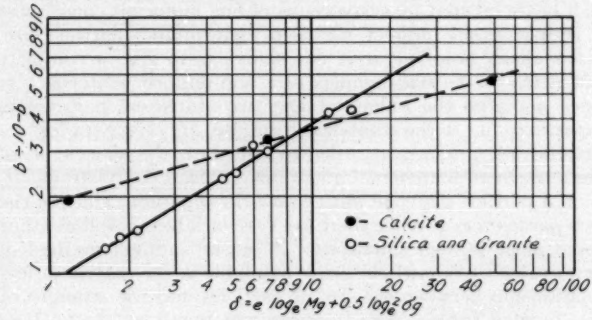
$$\log\left(\frac{b}{10-b}\right) = \log k + m \log Mg + mf \log^2 \sigma_g.$$

Dividing through by m and transposing, this becomes

$$\frac{1}{m}\left[\log\left(\frac{b}{10-b}\right) - \log k\right] - \log Mg = f \log^2 \sigma_g.$$

Plotting the expression on the left of the equality sign against $\log^2 \sigma_g$ on arithmetic paper must give a straight line having a slope of f and with its origin at zero, when the proper value of f is chosen, that is to say, when b is made to vary with size in the true manner. The variation of b with Mg, δ and Δ was examined in this way with results as shown in Fig. 4. Com-

FIG. 5.



Relation between the degree of polarization of the Tyndall beam and the Arithmetic Mean diameter of suspended particles.

paring the theoretical curves with experimental data, it is seen that whereas a satisfactory fit is given in the case of δ, there is a tendency in the other cases for the plotted points to depart from the curves when the value of σ_g increases. In the case of δ the deviations are fairly well distributed above and below the theoretical line, but definite trends are indicated in the other two cases. Thus it may be concluded from these data that the degree of polarization of the light scattered by sus-

pensions of finely divided materials is a function of the arithmetic mean diameter of the particles. The relationship is shown in Fig. 5 and is described mathematically as follows:

$$\log\left(\frac{b}{10-b}\right) = \log k + m \log Mg + 1.1513\, m \log^2 \sigma_g \cdots \quad \text{I.}$$

The data for silica and granite plot on a single line whereas the data for the calcite samples fall on a separate line having different values of m and k. This is to be expected in view of the fact that their indices of birefringence differ markedly, being + 0.172 for calcite and − 0.009 for quartz (5). The effect of birefringence upon the degree of polarization, of course, cannot be determined from the data given in the present paper.

Value of Polarization Measurements in Studies of Particle Size.—Measurement of the per cent. polarization of the Tyndall beam created by suspensions of fine materials constitutes a simple, rapid indirect means of determining particle size. Used alone, however, it is not sufficient to give a complete definition of the size-complex of a non-uniform material. It does not give the values of the two statistical parameters separately but in the combined form, $\log Mg + 1.1513 \log^2 \sigma_g$. On the other hand, in order to calculate the values of all the "average diameters," and thus obtain a complete definition of particle size, one must know the separate values of the two parameters. Since there are two variables, it follows that there must be two equations. A second indirect method of determination of particle size is available in the mathematical relationship between the size of particles and the strength of the Tyndall beam. The equation was found by the authors (loc. cit.) to have the following form:

$$\log Tc = \log c - \log Mg - 5.7565 \log^2 \sigma_g \cdots \quad \text{II.}$$

when Tc = Tyndall reading for a known concentration,
C = constant, depending upon concentration and optical properties of material and characteristics of apparatus.

According to this equation, the strength of the Tyndall beam for constant concentrations is a function of the Mean Specific Surface diameter. The two equations may therefore be com-

bined to eliminate one variable giving the relationship that follows:

$$\log Mg = \frac{1.5}{m}\left[\log\left(\frac{b}{10-b}\right) - \log k\right] + 1/3\,(\log Tc - \log C)\cdots \quad \text{III.}$$

The constants, C, k, and m, are determined by the physical properties of the material in question and by the characteristics of the apparatus. For silica, granite and calcite, they have been determined in our apparatus to be as follows:

TABLE IV.

Value of Constants in Equations I, II, and III.

Material.	Constant.		
	C.*	k.	m.
Silica	74.1	0.893	0.627
Granite	74.1	0.893	0.627
Calcite	113.8	1.860	0.291

* For suspensions of 50 mg./liter of water.

Substituting these values in equation III, the value of Mg may be determined from observed values of b and Tc. The value of σ_g may then be calculated from either equation I or II.

TABLE V.

Calculated and Observed Values of Mg and σ_g.

Sample.	Mg.		σ_g.	
	Cal.	Obs.	Cal.	Obs.
Silica E	1.67	1.73	1.76	1.42
" 6	1.84	1.85	1.81	1.77
" D	4.56	4.4	1.15	1.34
" 5	4.46	4.6	1.59	1.63
" C_1	6.6	6.6	1.35	1.33
" A	9.1	9.2	2.05	2.00
" A_2	9.7	12.0	1.89	1.80
" B_1	13.9	14.5	1.49	1.40
Granite 12	1.31	1.45	2.04	1.69
Calcite 14	42.7	47.0	1.44	1.32
" 17	7.14	6.1	1.45	1.60
" 18	0.83	1.15	2.28	1.35

The values of Mg and σ_g have been calculated from the twelve samples studied [3] and are compared with the observed values in Table V. The average deviation of the observed from the calculated values is approximately ten per cent. in each case.

SUMMARY.

The relation between particle size and the degree of polarization of the Tyndall beam created by suspension of non-uniform particulate substances was investigated for three materials (silica, granite, and calcite) ranging in size from one to fifty microns. The degree of polarization was found to be a function of the arithmetic mean diameter of the material. The optical property of birefringence was also found to be a determining factor although its effect was not studied quantitatively. It is shown that by combining the equation expressing the relation between particle size and strength of Tyndall beam with the mathematical relation between degree of polarization and particle size, an indirect method of obtaining a complete definition of particle size is given. Particle size values calculated from observed Tyndall readings and measurements of polarization were found to be within approximately ten per cent. of observed values.

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5. "Mineralogy." A. H. Phillips. New York: Macmillan Company, 1912, p. 168.

[3] Values of Tc were reported in our previous paper (1).

THE EXTERIOR BALLISTICS OF THE ARROW.

BY

F. L. ENGLISH, B.S.

I. INTRODUCTION.

Having become interested in archery, chiefly from a scientific rather than the sport viewpoint, the following investigation was undertaken to determine the principal characteristics of arrow flight. The literature of the subject is concerned chiefly with the history of the bow and with precepts of a rather empirical nature applying to the construction of tackle and the art of shooting. With the exception of Dr. Hickman's discussion of interior ballistics,[1] nothing in the nature of a scientific analysis of any phase of the subject is available, so far as the writer is aware. Moreover, the flight of low velocity projectiles in general seems to have received little attention, the rifleman and artillerist being concerned with velocities in excess of about 1000 ft./sec.

The present investigation, which is part of a more extended study of the theory of archery in general, has two major objects: the first, to determine the inherent accuracy of the arrow, independent of bow and release errors, and the essential factors determining accuracy; the second, to derive mathematical expressions describing the more important ballistic features of arrow flight.

II. THE THEORY OF ARROW FLIGHT.

As a result of the great difference in velocities encountered in the arrow and the modern bullet as well as the entirely dissimilar physical nature of the two types of projectile, the rather empirical system of equations that has been established by the artillerist is not applicable to the arrow. In the derivation of equations for arrow flight, two avenues of approach are open; one, consisting in modification of the existing ballistic formulas to include the inherent peculiarities of the

[1] JOUR. FRANK. INST., 208, 521 (1929).

arrow; the other, to attempt a new derivation based on purely theoretical grounds. The latter, being the more satisfying from the scientific standpoint, has been chosen.

According to Stoke's Law, the acceleration of a particle moving through a resisting medium is a linear function of the velocity. A projectile in flight is subject to two accelerations; one of negative sign acting tangent to the trajectory, the other acting vertically, being the sum of the positive acceleration of gravity and a negative quantity due to the air resistance of fall. The absolute values of these depend upon the relative densities of the particle and of the resisting medium, but in the case of the projectile passing through air, the air density is so small a fraction of the density of the projectile that it can be neglected and the acceleration considered a function of the weight.

Denoting the negative tangential acceleration by a and the net vertical acceleration by f, it follows from the above that,

$$a = \frac{KV}{W} \qquad \text{and} \qquad f = g - z,$$

where K is a constant; V, the initial velocity; W, the weight; g, 32.2 and z the negative acceleration of fall. z will therefore be proportional to the falling velocity, v, and inversely as the weight, or

$$z = \frac{V}{W} C',$$

but v depends upon the maximum height attained by the projectile, which in turn is a function of $V^2 \sin^2 \alpha$, where α is the angle of projection. Making these substitutions,

$$f = g - \frac{V^2 \sin^2 \alpha}{CW}. \qquad (1)$$

The acceleration, a, in addition to V and W, is modified also by the air density, δ, the cross-sectional area of the shaft and a coefficient of form, i, depending upon the shape of the head, stream-lining of the tail, feather shape and area, etc. In archery, since the total range of shaft diameters is small, (0.3 to 0.4 inch) and because the displacement resistance of the section is small in comparison with the skin friction of

the shaft and feathers, variations in diameter can be included in the coefficient of form. Theoretically, these factors affect z also, but the effect is negligible. The complete value of a is therefore,

$$a = \frac{Ki\delta V}{W}. \tag{2}$$

i is taken as 1.00 for a shaft of 0.355 inch diameter carrying any of the three feather types described later, since otherwise similar shafts yielded approximately the same range irrespective of the feather style. If, however, feathers differing widely in area from these are used, corresponding modification of i must be determined by experiment. For a shaft of 0.303 inch diameter, test shootings yielded a value of 0.85 for i, which by coincidence is almost exactly the ratio of the diameters, 0.303 : 0.355. It is probable that this ratio would apply equally well to shafts of other diameters. Variation in length from 28 to 31 inches has no appreciable effect upon the value of i.

75 deg. F. and 30 inches barometric pressure are taken as standard for δ, since these conditions are about the average under which archery is normally practiced. Variations in δ are therefore given by

$$\delta = \frac{\text{Bar. Pres.}}{30} \times \frac{535}{460 + t}. \tag{3}$$

Considering a body projected at an angle α to the horizontal, in time t, it will have traversed lateral and vertical distances, respectively,

$$x = \left(Vt - \frac{a}{2}t^2 \right) \cos \alpha, \tag{4}$$

$$y = \left(Vt - \frac{a}{2}t^2 \right) \sin \alpha - \frac{f}{2}t^2$$

$$= Vt \sin \alpha - r\frac{t^2}{2}, \tag{5}$$

in which r represents the compound acceleration $a \sin \alpha + f$.

A. The Range Equation.

Solving (5) for t, substituting this value in (4) and puting $y = 0$, an expression for the horizontal range is found:

$$R = \frac{V^2 \sin 2\alpha f}{r^2} \tag{6}$$

Using the data of the outdoor range shootings (see Table IV), the values of C and K in equations (1) and (2) were established as 4.0 and 36.6. It is evident from (6) that the angle of elevation for maximum range is not 45 deg., as is the case in the absence of air resistance, but a somewhat smaller angle. With the types of arrow studied, the maximum occurs at about 42 deg., the exact value depending upon the weight and velocity.

B. The Trajectory Equation.

From (4),

$$t = \frac{V \cos \alpha \pm \sqrt{V^2 \cos^2 \alpha - 2ax \cos \alpha}}{a \cos \alpha}.$$

Substituting this value in (5) and simplifying, the trajectory equation becomes,

$$y = \frac{V \sin \alpha}{a}(V - \sqrt{V^2 - 2ax \sec \alpha}) - \frac{r}{2a^2}(V - \sqrt{V^2 - 2ax \sec \alpha.})^2 \tag{7}$$

C. The Time of Flight.

Differentiating (5) and putting $dy/dt = 0$, we obtain the time required for the arrow to reach its maximum height and since the time of fall from this height is equal to the time of rise to it, the total time of flight is

$$t = \frac{2V \sin \alpha}{r}. \tag{8}$$

D. The Maximum Height of Trajectory.

Substituting $t = \frac{V \sin \alpha}{r}$ in (5), the maximum height is

found to be,

$$H = \frac{V^2 \sin^2 \alpha}{2r}. \tag{9}$$

Making the same substitution in (4), the abcissa of the vertex is,

$$X = \frac{(V^2 \sin 2\alpha)(r + f)}{4r^2}. \tag{10}$$

E. The Angle of Fall.

From (4),

$$dx/dt = \cos \alpha \, (V - at),$$

from (5)

$$dy/dt = V \sin \alpha - rt.$$

Therefore,

$$dy/dx = \tan \phi = \frac{V \sin \alpha - rt}{\cos \alpha \, (V - at)}, \tag{11}$$

where ϕ is the angle of inclination to the horizontal at any point of the trajectory. Substituting the value of t representing the total time of flight, an expression is obtained for ω, the angle of fall:

$$\tan \omega = \frac{r \tan \alpha}{r - 2a \sin \alpha}. \tag{12}$$

F. The Remaining and Striking Velocities.

The vertical and horizontal components of the velocity at any time being dx/dt and dy/dt, the remaining velocity is,

$$V_R^2 = (dx/dt)^2 + (dy/dt),^2$$

from which,

$$V_R = \sqrt{V^2 - 2ax \cos \alpha - 2ry}. \tag{13}$$

When $y = 0$, the striking velocity is obtained,

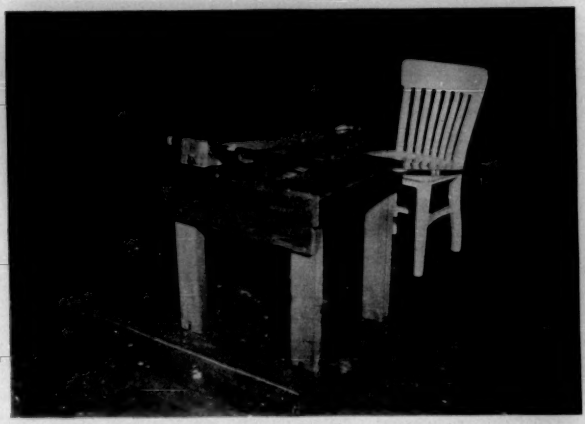
$$V_\omega = \sqrt{V^2 - 2ax \cos \alpha}. \tag{14}$$

III. EXPERIMENTAL DATA.

A. Apparatus.

1. The Shooting Machine.—The general features are illustrated in Figs. 1 and 2. For the sake of compactness and to

FIG. 1.



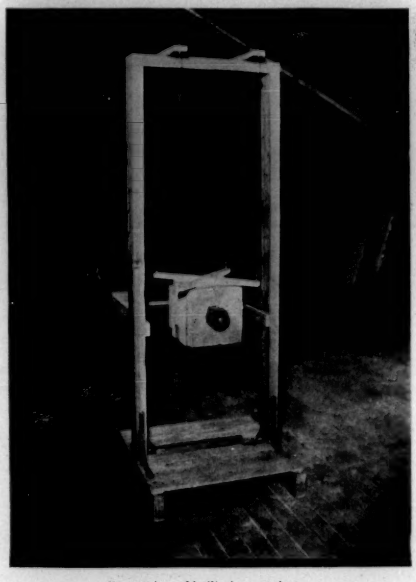
Front view of shooting machine; bow full drawn with arrow in place.

FIG. 2.

Rear view after discharge of arrow.

somewhat facilitate construction, it was built to operate the bow in a horizontal rather than the usual vertical plane. The arm carrying the bow clamp, arrow guide, etc., was hinged at the rear and supported forward by a heavy steel quadrant which could be clamped rigidly by two bolts at any desired angle of elevation. The essential feature is the arrow guide

FIG. 3.

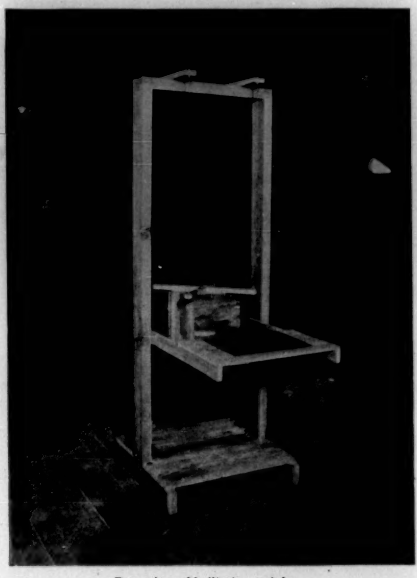


Front view of ballistic pendulum.

consisting of a V-shaped groove, constructed with the greatest possible accuracy, supporting the arrow throughout its entire length, the forward end being slightly above the level of the bow so that the arrow does not touch the bow in passing. The outer edges of the arrow guide were also cut away so that the feathers do not come in contact with any part of the ap-

paratus. To prevent a downward thrust of the bowstring upon the arrow at the nock, guide strips were run along the sides of the groove block upon whose upper surfaces the string traveled. These string guides were adjustable to various shaft diameters so that the string at all times coincided with

FIG. 4.



Rear view of ballistic pendulum.

the plane of the nock, thus eliminating all thrust other than in the forward direction. The string was released from full draw by a simple trigger mechanism also designed to prevent vibratory motion of the string.

During the indoor test shooting, the entire apparatus was fastened rigidly to the floor by means of four iron angles. Outdoors, four stakes were driven into the ground and the legs of the machine clamped thereto.

2. *The Ballistic Pendulum.*—As no chronograph was available, a ballistic pendulum was constructed, illustrated in Figs. 3 and 4. A four-point support was used, each wire having an adjustable attachment at the top so that the weight could be uniformly distributed. The bob was made of wood, faced with a 1.5 inch layer of cork and provided in the center with a socket in which two 3 inch diameter corks glued top to top were placed to receive the arrow.

The back of the bob carried a 1/8 inch diameter iron wire stylus attached by a special hinge permitting free motion in a vertical plane only. The sharpened tip of the stylus rested upon a smoked glass plate. Dimensions of the apparatus need not be given, but may be estimated from the relative length of the 15 inch ruler lying upon the base.

The principal errors of the ballistic pendulum arise from bearing friction and air resistance. The sum of these was determined by permitting the bob to swing through an arc of about 6 inches and simultaneously moving the glass plate laterally at a uniform rate. A continuous wave line decreasing in amplitude was thus traced, the magnitudes of successive decreases being equal. The correction so determined is included in the following formula:

$$V = \frac{W + w}{w}\left(\frac{D + K}{24}\sqrt{\frac{g}{L}}\right), \qquad (15)$$

where

V = arrow velocity, ft./sec.
W = weight of bob, lbs.
w = weight of arrow, lbs.
D = full amplitude of swing, inches.
K = correction for friction = 0.24 inch.
g = gravitational constant, = 32.2
L = effective length of pendulum determined by vibration period, = 2.63 ft.

If the arrow does not strike directly in line with the center of gravity, a rotary as well as a translatory motion will be imparted to the bob. A merely casual consideration might lead one to suppose that the energy of rotation subtracts from the energy producing translation and hence shortens the swing. The above equation is, however, derived upon the

equality of momenta and not total energy, the motion of the center of gravity of the bob being therefore independent of the point of impact and degree of rotation. The only way an error can be introduced as a result of rotation is for the stylus not to be pointing directly backward when the bob has reached its extreme backward, or forward position. If the rotational period is one-half the swing period, both the bob and the stylus attain their extreme positions simultaneously and there is no error. In this particular pendulum, the swing period is 1.80 sec. and the rotational period 0.86 sec., the error of non-synchronization being therefore negligible.

3. The Bow.—The same bow was used in all the test shooting. It was a three-ply composite of 46 to 51 pounds drawing weight, depending upon the temperature, composed of Osage Orange on the belly, yew for the middle layer and whalebone on the back. Incidentally, it may be stated that, within the writer's experience, whalebone is far superior to any of the commonly used backing materials.

4. Arrows.—Three principal weights of test arrows were used, all made accurately to the same dimensions; i.e., 31 inches long by 0.355 inch diameter, $\pm$ 0.003, tapered through the rear 4 inches to a diameter of about 0.2 inch at the nock. These arrows were made of Sitka Spruce, Ash and Lemonwood, giving approximate weights of 425, 595 and 730 grains, respectively. Certain other arrows were also used incidentally, the data of which will be found in the tables. The unusual length of 31 inches, as compared with the standard of 28, is explained by the fact that the writer habitually uses the Asiatic Draw in target shooting (traction with the thumb) instead of the usual Mediterranean (traction with the fingers). Since the thumb is much shorter than the fingers, a correspondingly longer arrow can be accommodated with the same hand positions as used in the Mediterranean Draw.

Selected turkey feathers were used in all cases, but in three types as follows:

a. 3″ × 1/2″, area, one side of single vane, 1.11 in.²
b. Balloon type, 2 1/4″ × 5/8″, area, 0.96 in.²
c. 3″ × 3/8″, area, 0.92 in.²

The feathers were attached by means of an especially designed

clamp thus reducing to a minimum errors of spacing and alignment. Immediately prior to the test shooting, the feathers were steamed and pressed. The shafts were also tested against a steel straight-edge.

B. Experimental Shootings.

Through the courtesy of the du Pont Company, space was made available for a 50 yard range in one of the research laboratories, thus eliminating wind errors. The indoor shooting may conveniently be considered under three heads; Accuracy, Velocity and Trajectory.

1. Accuracy.—Six or more arrows of each type were shot from the machine at a square of heavy paper mounted on a standard straw target at a range of 50 yards. An interval of 15 seconds was allowed between successive shots. Each group of arrows was shot three or more times at the same target thus giving a minimum of eighteen shots in each pattern. The center of impact of the hits was then determined in the usual manner and the diameter of the circle enclosing all the shots determined. Separate patterns were also taken for certain individual arrows, each one being shot ten times. The data of these tests are included in Table I below.

TABLE I.

Arrow Accuracies.

Arrow.			Arrows in Group. no.	Total no. Shots.	Deflection for 1 lb. in.	Arrow Factor.	Dia. of Enclos. Circle. in.
Length in.	Dia. in.	Weight gr.					
31	.355	426	6	18	.278	118	9
"	"	"	"	"	"	"	8
31.25	"	366	"	"	.390	143	16
30	.303	298	7	21	.510	152	18
31	.355	426	1	10	.278	118	3
"	"	596	1	10	.381	227	8
"	"	720	1	10	.309	230	10
30	.303	298	1	10	.510	152	6

Inspection of these results leads to the apparently anomalous conclusion that accuracy increases with weight to a certain point and then decreases again. This conclusion is partly true since accuracy is a function, not of weight alone but of

what the archer has vaguely called "spine" without ever accurately defining the term. It is evident, however, that spine is the inverse tendency of the shaft to bend while passing from the bow under the impulse of the string and therefore varies directly as the stiffness and inversely as the weight, for a given length. In testing various woods for their suitability for arrow material, the "Spine Factor" is conveniently expressed by the modulus of elasticity divided by the specific gravity. A more significant figure to the archer, since it takes into consideration the length and diameter of the individual shaft, is the "Arrow Factor," determined by supporting the arrow one-half inch from each end, applying a load of one pound at the center and multiplying the weight of the arrow in grains by the deflection in inches. The relative arrow accuracies given in the table are now seen to be roughly in inverse ratio to the Arrow Factor.

The circles of dispersion for a group of arrows compared with that for a single arrow of the group indicates the difficulty of constructing a set of arrows of uniform performance, for the greatest care was taken in making individuals of these groups as nearly alike as possible in length, diameter, weight and feathering.

2. Initial and Striking Velocities.—In making the velocity determinations, the pendulum was set up successively at 10 yard intervals, but in the following table only the data of the longer ranges are given, as being sufficient to show the degree of correspondence between the observed values and those calculated from equation (14). In the column headed "D" are given the deflections, (each one being an average of several

TABLE II.

Striking Velocities.

Arrow Wt. lbs.	Range ft.	Angle of Elev.		Weight Bob. lbs.	D. ins.	Velocity, ft./sec.	
		Deg.	Min.			Found.	Calc.
.0615	0	0	0	11.11	5.62	155.4	——
"	150	6	15	11.04	5.15	141.8	142.2
.0851	0	0	0	11.11	6.97	138.5	——
"	120	6	10	11.04	6.65	131.4	130.9

tests), of the bob which, when substituted in (15) give the velocities. The drawing weight of the bow was 46 lbs., the temperature 84° F. and the barometric pressure 30.1 inches.

3. Trajectory.—The trajectory data for various weights of arrow were obtained by shooting from the machine through a tissue paper screen placed successively at measured distances from the bow. These data, in comparison with the corresponding values calculated from equation (7), are as follows:

TABLE III.

Arrow Trajectories.

Range, ft.	Height, ft.			
	S. Spruce.		Lemonwood.	
	Found.	Calc.	Found.	Calc.
0.0	0.00	0.00	0.00	0.00
27.5	2.08	2.14	2.80	2.96
48.8	3.23	3.19	4.20	4.31
70.2	3.66	3.61	5.03	5.00
90.5	3.56	3.52	4.83	4.84
111.3	2.91	2.80	3.77	3.80
125.6	2.14	1.99	2.69	2.81
139.8	0.80	0.77	1.06	1.07
150.0	0.00	−0.02	0.00	−0.01

Weights: Spruce, .0590; Lemonwood, .1036 lb.
Initial vel.: Spruce 167.9 Lemonwood, 141.4 ft./sec.
Angles of elev.: Spruce, 5° 20′ Lemonwood, 7° 25′
Max hts. Eq. (9): Spruce, 3.65 Lemonwood, 5.04 ft.
Temp. °F.: Spruce, 82 Lemonwood, 70
Bar. pres.: Spruce, 29.85 Lemonwood, 30.10

4. Range.—The final shootings, whose primary object was the evaluation of constants, were made with the machine set up in a level field outdoors. The course was roughly surveyed and angular correction made to compensate slight irregularities. The atmospheric pressure was 30.0 inches, the temperature, 74° F., there was no perceptible wind and the sky was completely overcast, thus preventing temperature changes in the bow due to direct sunlight. Experimental values given in the following table are of course averages of several shots.

TABLE IV.
Arrow Ranges.

Arrow.	Range, ft.							
S. Spruce								
Angle	*10° 20′*	*15° 5′*	*19° 55′*	*24° 50′*	*30° 0′*	*35° 0′*	*40° 0′*	*45° 0′*
Range, found	245	318	386	438	488	514	530	515
Range, calc.	240	325	390	454	497	522	532	524
Ash								
Angle	10 30	15 10	19 55	25 0	30 0	35 0	40 0	45 0
Range, found	210	284	348	405	443	468	491	487
Range, calc.	203	277	341	396	437	465	478	468
Lemonwood								
Angle	10 35	15 20	20 5	25 0	30 0	35 0	40 0	45 0
Range, found	184	253	318	365	404	425	436	432
Range, calc.	182	249	311	361	400	426	442	443
S. Spruce, .303″ dia.								
Angle	10 10	15 0	19 50	24 50	30 0	35 0	40 0	45 0
Range, found	267	353	430	492	531	554	577	566
Range, calc.	272	368	444	505	547	572	575	560

Initial Vels.: S. S. = 158; ash = 141; lem. = 132; .303″ = 174 ft./sec.
Weights: " 431; " 596; " 735; " 298 grs.
i, Eq. two, for the .303″ dia. was found to be .85; all others, 1.00.

In a similar series of shootings, the time of flight was taken. Since the timing was done with a hand operated stop watch reading to only 1/5 second, close correspondence between the observed and calculated times is not to be expected. The two sets of results are, however, sufficiently in accord to indicate the approximate correctness of the time equation.

TABLE V.

Time of Flight.

Angle of Elev.		S. Spruce.		Ash.		Lemonwood.		S.S. .303"	
Deg.	Min.	Found.	Calc.	Found.	Calc.	Found.	Calc.	Found.	Calc.
10	30	2.0	1.73	1.8	1.59	1.8	1.49	2.0	1.83
25	20	4.2	3.95	3.8	3.63	3.6	3.43	4.2	4.13
40	20	6.2	6.08	5.8	5.52	5.4	5.18	6.4	6.50

Initial Vels.: 163, 146, 136, 177, ft./sec.
Weights: 431, 596, 735, 298, grains.

IV. CONCLUSIONS.

A system of equations has been established describing the salient points of arrow ballistics. Values calculated from these formulas check experimental determinations within approximately ± 1 per cent., which represents about the limiting accuracy of such determinations since they are affected not only by the rather high errors inherent in wooden equipment but also, in the outdoor shooting, by very small variations in wind velocity. For example, a wind of one mile per hour is sufficient to account for an error of nearly ten feet in a range of six hundred feet or 1.7 per cent.

It is probable that these equations would apply equally well, with suitable change in constants, to other types of low velocity projectiles and it is possible that a slight modification might adapt them to the ballistics of higher velocities.

Laboratory Method of Producing High Potentials. G. BREIT, M. A. TUVE AND O. DAHL. (*Phys. Rev.*, Jan. 1, 1930.) For the investigation of atomic structure and for the testing of theories it is desirable to have in the laboratory means of imparting high velocities to particles. The authors have designed a Tesla tube for this purpose. With the coils in oil and excited by 120 sparks per sec. a voltage of 3,000,000 is obtained. This is extended to 5,200,000 volts when the oil is under pressure. The use of the oil prevents both corona and sparking. For comparison with radioactive sources we recall that the number of α-particles emitted by a gram of radium per second is about 3.5×10^{10}. Thus at 5,000,000 volts one spark a second has sufficient power to drive 0.75×10^{12} α-particles equivalent to 21 grams of radium, and 120 sparks a second would be equivalent to 2600 grams. Such α-particles would have an energy of 10,000,000 electron volts, at least 2,000,000 higher than the highest energy α-particles obtainable from radioactive sources."

G. F. S.

ERRATA.

THE DYNAMICAL THEORY OF ALTERNATING CURRENT MACHINERY AND THE PROBLEM OF THE STABILITY OF POWER SYSTEMS

BY

WYATT HAWKINS INGRAM,

September 1930, page 327.

P. 329, line 6, change n to $2n - 1$.
line 7, change $n + 1$ to $2n + 1$.
line 7, change n to $2n$.
line 8, change "generalized" to "cannonical."
P. 336, eqn. (26), omit line under d_i.
eqn. (27) should read: $C_1, C_2 = K \pm 2j \mp 4l \pm 3$,
$C_3, C_4 = K \pm 1$.
eqn. (28) change 21 to $2l$.
P. 340, eqn. (41), change ϕ to γ.
P. 341, line 12, change ϕ to ψ.
line 13, change ϕ to ψ.
line 20, center is at $(e_0/2r)$.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

HEIGHT OF KENNELLY-HEAVISIDE LAYER.

A paper to be published in the November number of the *Bureau of Standards Journal of Research* will present experimental results obtained in measurements of the virtual height of the Kennelly-Heaviside layer by the radio echo method. The procedure is essentially that first used by Breit and Tuve and consists of the receiving and oscillographic recording of signals from a high-powered transmitter which is sending out pulses of extremely short duration with sufficient intervals of no emission between pulses to record the echoes. The time interval between the arrival of the ground wave and the first echo is used to calculate the virtual height. The report covers daytime observations made each week between January 16 and June 19, 1930. The frequencies used were 4045 and 8650 kc. Two evening tests are also described. Curves are given comparing heights with sunspot numbers and magnetic character. Records taken on April 28, 1930, during a solar eclipse, are shown.

NATIONAL STANDARD FOR TESTING POWER LINE INSULATORS.

A further step in the nation-wide protection of high voltage electrical transmission lines which have been put into service throughout the country during the past several years to carry power at voltages as high as 220,000 was taken on October 15 with the approval by the American Standards Association of a national standard for testing power line insulators.

This standard, prepared through the coöperation of the American Institute of Electrical Engineers, the National Electrical Manufacturers Association, the National Electric Light Association, the National Bureau of Standards, and other organizations concerned with high voltage transmission, assures against insulator failure the lines carrying an increasing percentage of the nation's power supply.

The standard will enable laboratories in New York and in

* Communicated by the Director.

California to use the same authoritative tests to determine the reliability of insulators. In several of the laboratory tests, voltage applied to the insulator is increased at the rate of 10,000 volts every fifteen seconds until failure occurs. The final voltage must be far above the greatest voltage which the insulator either singly or in series with other insulators will be required to withstand.

It is pointed out that the suspension insulators used for cross country transmission lines must be tested not only for their resistance to high voltages but also to the tremendous stresses set up by wind and by the ice which may cover the lines in winter, especially since the transmission towers from which the lines are suspended by means of the insulators are in some places as much as a mile apart.

ULTRA-VIOLET TRANSMISSION OF SEA SHELLS.

What is known as "Philippine Window Shell" or "mother of pearl" is obtained from a mollusk (*Placuna placenta*) and is extensively used for decorative lamp shades. This shell is composed of calcium carbonate, is translucent, and has a light pink color when not weathered.

Several years ago the bureau conducted some tests on the ultra-violet transmission of this material to determine whether it prevented the passage of rays injurious to the eyes. It was found that thin lamina of the material are transparent to light waves as short as 250 millimicrons, but the complete shell, which is 0.6 to 1.5 mm. in thickness, is too inhomogeneous to transmit rectilinearly in any one direction, an appreciable amount of ultra-violet radiation. Moreover, ordinary incandescent lamps with which such shades were being used, do not emit sufficient ultra-violet radiation to injure the eye.

Recently, the subject has arisen of using these sea shells in the same way as the special window glasses, for transmitting ultra-violet solar radiation for healing purposes. An examination was, therefore, made a short time ago of new and of partially weathered material. Measurements were made of the total amounts of wave-lengths 290 to 313 millimicrons, diffusely transmitted in all directions, and also rectilinearly through the material, which in this instance was only 0.7 millimeters in thickness.

The integrated ultra-violet, of wave-lengths 290 to 313 millimicrons, diffusely transmitted by the new sample was about 14 per cent. of the total incident radiation, and about 11 per cent. by the sample which had been exposed to the summer sun for 145 days. For samples of average thickness, 1.5 mm., these values would be reduced to 3.8 and 3.3 per cent. respectively. This refers to the total amount of ultra-violet transmitted in all directions throughout a room.

Tests were also made with this material placed directly in front of the entrance slit of the spectroscope and it was found that less than 2 per cent. of the ultra-violet, at 302 millimicrons, was transmitted rectilinearly. In contrast, it is to be noted that the special window glasses transmit 30 to 70 per cent., and quartz 90 per cent. of these rays.

It is, therefore, concluded that while sea shell has the interesting property of transmitting (diffusely) an appreciable amount of ultra-violet radiation, the total amount transmitted along a straight line is too low, in comparison with the special window glasses, to be effective in ultra-violet light therapy.

INTERFERENCE MEASUREMENTS IN THE FIRST SPECTRA OF KRYPTON AND XENON.

The wave-lengths of the stronger arc lines of krypton and xenon have been redetermined at the bureau by the use of Fabry-Perot etalon interferometers. Etalons of 15, 25, and 40 mm. length were used in obtaining the data. Discharge tubes operated so as to emit only the spectrum of the neutral atom of the gas under investigation supplied the radiation. Part of the xenon lines were observed as impurity lines in the radiation from a krypton-filled tube as well as in tubes containing pure xenon only. The secondary standards of neon photographed simultaneously with the krypton and xenon spectrum furnished the comparison. The values of neon wave-lengths used were those given by Burns.

Interferometer measurements of a sufficient number of krypton lines have been made to permit fixing the relative values of all the $1s$, $2p$, and $3p$ terms to a high degree of precision. The accuracy of the term values is such that the average deviation of calculated term combinations from the observed wave numbers is one part in twenty million. The

corresponding set of terms in the xenon spectrum, except $2p_{10}$, were determined also with increased precision from interference measurements. In addition to these, four of the $4p$ terms have been recalculated. Nearly three-fourths of the combinations permitted by the selection rule have been observed. The exact location of the combinations in the infra-red region not photographically accessible can now be predicted with certainty. Such lines should prove useful wave-length standards for the infra-red region.

With the resolving power employed none of the krypton lines showed hyperfine structure. It is apparent from the extremely small variations of the "constant differences" that the intensities of any unobserved satellites are too low to affect the wave-lengths. Five of the xenon lines showed satellites. Further work is contemplated in the examination of the lines of both spectra for hyperfine structure.

The results of this study will be presented in detail in the November number of the *Bureau of Standards Journal of Research*. Comparisons are made with earlier interferometer measurements. The close agreement of the bureau's results with those of other observers, as well as the small differences between the separate observations, indicate that the wave-lengths of the radiation emitted by krypton or xenon are reproducible within the limits set by the probable error of the observations. For the intense green and yellow lines of krypton, for which Perard, at the International Bureau obtained wave-lengths 5570.2892 and 5870.9154 A., the Bureau of Standards obtains 5570.2890 and 5870.9153 A.

EFFECT OF ADDING BISMUTH TO LEAD ALLOYS.

Metallic bismuth resembles lead in many of its properties such as its high atomic weight, and the two metals frequently are found in the same ores. These facts suggested to the bureau a study of certain lead base alloys to see if the addition of bismuth would improve their desirable properties. The similarity in properties of antimony and bismuth, coupled with the fact that antimony is one of the best known hardening additions for lead alloys, were additional factors which indicated the possible usefulness of bismuth in this field. This

study was undertaken as part of an investigation seeking to extend the uses of metallic bismuth.

Tensile strength, hardness, and elongation were determined for (1) lead-bismuth alloys containing up to 50 per cent. bismuth, (2) lead-tin alloys containing up to 50 per cent. tin, (3) a number of type metals, and (4) fusible alloys. The freezing-point characteristics and behavior during compression were determined for some of the specimens. The effect of additions of small amounts of bismuth, up to 5 per cent., on the properties of certain type metals is shown. This investigation will be reported upon in greater detail in the November number of the *Bureau of Standards Journal of Research.*

THERMAL EXPANSION OF SOME SODA-LIME GLASSES.

In connection with work on the physical properties of some soda-line-silica glasses the thermal expansions of 20 glasses have been determined from room temperature to their initial softening temperatures. The compositions vary from approximately 54 to 80 per cent. silica, 38 to 12 per cent. soda, and 3 to 15 per cent. lime. The expansions were measured by the interference method described by Peters and Cragoe, and an effort has been made to evaluate the expansion of these glasses in terms of their lime and soda content. So far attempts at correlation have been confined to the data obtained from room temperature (approximately 30° C.) to the "critical temperature" or that temperature at which the rate of expansion begins to increase.

The expansion of any of the glasses in the series can be computed with a fair degree of accuracy from the following expressions:

$$E_t = K_t 1.35(\text{CaO} \quad \text{Na}_2\text{O}) - 0.006(\text{CaO} \quad \text{Na}_2\text{O})^2 - 0.65\text{CaO}$$

In this expression E is the expansion in microns per centimeter at any temperature t, and the value for K at certain temperatures is as follows:

$t =$	30°	100	200	300	400	500
$K_t =$	0	0.21	0.57	1.00	1.49	2.00

Temperatures are expressed in degrees C. and the lime and soda are expressed as percentages.

It must be borne in mind that the above expressions hold only between room temperature and the "critical temperature."

SOUNDNESS OF LIME.

Lime used for the finish coat of plaster sometimes causes a type of failure known as "popping." Small particles of the finish coat expand, disrupting the surface which causes some of the plaster to fall off, leaving a pit or "pop." This is probably caused by the slow hydration of the constituents of the lime. The present method of testing for this type of failure as adopted by the American Society for Testing Materials involves steaming the lime at atmospheric pressure. Since this method did not appear severe enough, it was proposed to subject the lime to steam under pressure. The lime, mixed with enough calcined gypsum to prevent shrinkage, was spread as a thin coat on a porous procelain base. After standing for an hour, or until the calcined gypsum was set, it was steamed for two hours at a steam pressure of 120 lbs./in.^{2} in an autoclave. During the steaming the particles hydrate and expand causing "popping" or unsoundness. This method is essentially that described in Technical News Bulletin No. 144 (April, 1929) with the exception that steaming at 120 pounds pressure has been found preferable to the 20 to 25 pounds pressure as reported previously.

In order to compare the two methods, plastered panels were made using lime for the finish coat. Samples of the limes were tested by both methods.

Thirty-three panels were made up and allowed to age. Of the 33 panels, 24 have developed "pops." Twenty-three of them tested unsound on steaming at 120 pounds pressure, whereas only 12 tested unsound by the A. S. T. M. method. The agreement, therefore, appears to be much better for the autoclave method than for the A. S. T. M. method.

DETERIORATION OF PAPER.

A summarization of the activities of the Bureau of Standards relative to the causes of paper deterioration was presented by B. W. Scribner at the recent annual meeting of the

Pacific Coast Section of the Technical Association of the Pulp and Paper Industry, at Portland Oregon.

Considerable progress has been made in measuring the permanence qualities of the current paper-making raw materials and papers. The tests used for this purpose are based primarily on consideration of paper as a cellulose material. Apparently a high degree of cellulosic purity, with a minimum of active chemical components, and sufficient strength for the intended use, are the prime requirements in paper for resistance to deterioration. The tests show that commercial papers are available, made from both rag fibers and wood fibers, which meet such requirements satisfactorily. Systematic collection and testing of old publications has also shown the importance of cellulosic purity, as the papers composed of fibers refined by chemical treatment are generally in good condition, while those containing crude fibers, such as ground wood, are generally badly deteriorated.

Through surveys of library storage conditions it appears that acid pollution of the atmosphere, light, high temperature, dampness, and dust are the leading external deteriorating influences. The effects of light and of atmospheric components on paper and paper-making materials are undergoing further study in the laboratory.

Studies of the relation of the various paper-making materials to permanence qualities of papers are being made in a practical way by paper-making trials in the bureau's paper mill. This work so far has dealt largely with wood fibers having a high degree of cellulosic purity and these have given very satisfactory test values. Studies of paper sizing materials have shown the desirability of limiting so far as possible the amounts of alum and rosin used in rosin sizing the papers. On the contrary, glue and starch used for surface sizing the papers appear to give them added protection against chemical deterioration.

The improvement and standardization of test methods used for determination of alpha cellulose, copper number, and acidity, all of which appear to have an important bearing on permanence, are receiving attention, and progress in this direction is reported.

EFFECT OF DENSITY OF PACKING ON INSULATING MATERIALS.

Within the past few years there has been great activity in the field of heat insulation, particularly for dwellings, and a large number of materials have been utilized in the manufacture of insulating products of various kinds. There are numerous other raw materials, now considered more or less waste, which may be equally suitable for this purpose.

Anticipating the need for additional data, a study has been conducted at the bureau of the insulating properties of various fibrous materials. Tests have been made on jute, cotton, flax, wood fibre, bagasse, cornstalk fibre, moss, excelsior, etc. From an insulation standpoint, alone, there is practically no choice between the different commercial grades of each material. The waste or poorest grades, therefore, may be commercially available for the manufacture of heat insulating materials.

Tests were made of each material packed to various densities covering as wide a range as practicable, and it was found that for each fibre there is an optimum density at which the thermal conductivity is a minimum or the insulation value a maximum. Where the only consideration is maximum insulation in a given space, this suggests that the materials should be packed at these optimum densities.

Considerable attention was given to the mechanism of heat flow, and it was found that for a given fibrous material and a given density, the heat conductivity may vary by several hundred per cent., depending entirely on the arrangement of the fibres. The maximum conductivity is obtained when the fibres are parallel to, and the minimum conductivity when the fibres are perpendicular to the direction of heat flow. The present methods of manufacture of fibrous sheet materials do accomplish to a large extent the orientation of the fibres so that they are most effective for insulation.

At very low densities it was found that the increase in conductivity was primarily due to radiation; air convection plays a very minor part.

This investigation will be fully described in the November number of the *Bureau of Standards Journal of Research.*

ANNUAL REPORT OF BUREAU OF STANDARDS FOR 1930.

The annual report of Dr. George K. Burgess, Director of the Bureau of Standards, to the Secretary of Commerce, covering the fiscal year ended June 30, 1930, will be released on November 18.

One of the most important developments recorded in this report is the realization after many years' effort of the Waidner-Burgess absolute standard of light, which may eventually supplant the carbon lamps now used as standards of candlepower by the various nations. The new standard was described in Technical News Bulletin No. 151, p. 107 (November, 1929). The brightness of the interior of a tube of fused thoria immersed in a bath of pure platinum at its freezing point has been found equal to 58.84 candles per square centimeter. The difficulties attending the actual setting up of this standard have been very great, but they have all been surmounted so that the process has been reduced to one of mere laboratory routine. A recommendation has been made by the bureau that this standard be accepted by the International Committee on Weights and Measures as a new international standard of light.

In the engineering world, an event of great significance was the signing by the President on May 14 of a bill creating a national hydraulic laboratory to be located at the bureau. This laboratory will study fundamental problems of hydraulics including flow of rivers and open streams, and will test all kinds of hydraulic machines and instruments. A committee to draw up plans for the laboratory has been appointed.

Developments in the radio field require the highest attainable precision in measurements of frequency. By means of a special installation of four quartz oscillators and auxiliary machinery including automatic photographic apparatus, it is now possible at the bureau to measure radio frequency with an error of only about two parts in 10 million.

To aid the aeronautic industry a special laboratory has been set up at Arlington, Va. in which each new type of commercial airplane engine is subjected to an endurance test for the Aeronautics Branch of the Department of Commerce. Certificates are granted by the Department only for those engines which meet the bureau requirements. Three engines

can be tested at one time at present and equipment for a fourth test stand will soon be installed.

The development of radio aids to air navigation is briefly touched upon. These have been described in recent numbers of this Bulletin. Methods of lighting the airways and landing fields have also been studied and many tests have been made on the special light alloys used in constructing airplanes and airships. To determine the effect of repeated vibration on duralumin a special machine is in use in which the specimen is floated on air and is caused to vibrate by a high speed air stream at a rate of 210 cycles per second. Through the use of this machine it is possible to carry tests to 200-million cycles or over.

Through an extensive coöperative investigation on the properties of railroad rails during the period of fabrication it has been found that owing to the low ductility of certain kinds of steel at the temperatures at which rails are rolled there is a tendency for the formation of nuclei within the rails from which transverse fissures may later develop in service. Certain changes in the manufacturing procedure are suggested as a means of correcting the evil.

Experiments on the tanning of sole leather have shown that chrome tanned leather retanned with vegetable material will wear from 25 to 27 per cent. longer than ordinary vegetable tanned leather. The effect of sulphuric acid on leather and paper has been studied and it has been shown that acid in amounts commonly present in the atmosphere of large cities has a very serious deteriorating effect.

The importance of using thoroughly purified fibers in paper intended for permanent records has been brought out. A study of old newspapers has shown that with the substitution of raw wood pulp for the more highly purified materials a marked decrease in the permanence of the paper took place. Many papers issued 30 or 40 years ago have almost completely deteriorated. In the semi-commercial plant maintained by the Bureau of Standards and Iowa State College at Ames, Iowa, wall-board one-half inch thick and twice as strong as any on the market has been produced from cornstalks. The process is now being used commercially.

Xylose has been successfully manufactured in an experi-

mental plant at Anniston, Alabama, and possible uses for this new sugar are being studied.

The experimental sugar refinery at the bureau has been operated on the first stage of the process of producing levulose from Jerusalem artichokes and the next step, the actual crystallization of the sugar from its water solution will be undertaken very shortly.

Under the auspices of the American Society for Testing Materials a cement reference laboratory has been established at the bureau to standardize testing procedure and methods in the numerous cement laboratories throughout the country. (See Technical News Bulletins Nos. 146, 150, 151, 154, and 156.) Inspection trips are made by the personnel of this laboratory and their services have been in constant demand.

In the field of optics progress is recorded on the mapping of spectral lines and in particular in search for a new and better fundamental standard of wave-length. A series of filters has been developed by which the character of artificial light sources can be changed to that of sunlight, and one of these has been recommended for adoption as an international standard by the Seventh International Congress on Photography.

A continued investigation on which progress is recorded deals with the development of methods for the fractionation of petroleum and the identification of its constituent hydrocarbons. This work involves laboratory technique of extreme difficulty, but good progress has been made and several publications issued.

In coöperation with the American Petroleum Institute, the American Gas Association, the Underground Pipe Products Institute, and the Cast Iron Pipe Research Institute, a beginning has been made of an extensive field investigation of protective coatings for underground pipe lines. This work supplements similar work which has been in progress for several years on the corrosive effect of soils on underground pipe.

The investigation which the Bureau has been conducting in coöperation with the American Society of Mechanical Engineers and other organizations on the determination of the properties of steam has formed the basis for a revision of the steam tables by international conferences in London and Berlin.

The Post Office Department is a branch of the Government which is making increasing use of the bureau's facilities. Considerable time has been spent in studies of automatic machines which have been proposed to the Department for adoption in its mechanization program. Among these were mail meters, where safeguards against fraud are of importance.

During the period under consideration an interesting extension of the bureau's simplified practice work has taken place. In the past this has been confined almost entirely to production, but recently simplified practice methods have been extended in the fields of distribution and consumption and important progress is being made on the simplification of containers and packing methods. Satisfactory progress is also recorded in the fields of specifications and commercial standards, standards having been adopted for a wide range of products from dress patterns to fuel oils.

The division of building and housing has coöperated with the new construction division of the Department on many problems connected with the Government's program of public construction.

The number of tests completed by the bureau during the year was 200,726 with a fee value of $683,614, a substantial increase over last year, when the figures were 173,512 and $544,402. One hundred and ninety-four papers were published in the regular series of the bureau and about 240 in outside journals.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, NOVEMBER 19, 1930.

The regular monthly meeting of the Institute was called to order by the President, Mr. Nathan Hayward, at eight-fifteen o'clock. He announced that this was the regular monthly meeting and immediately called upon the Secretary of the Institute for a statement of the business of the evening.

The Secretary, Dr. McClenahan, first announced with deep regret the death of Mr. James T. Wallis, an honored member of the Board of Managers, and read a minute which had been adopted by the Board of Managers of the Institute concerning Mr. Wallis. (This minute is published elsewhere in this number of the JOURNAL.)

The Secretary then called to the attention of those members of the Institute who had been workers in the campaign for funds last June the fact that invitations had been issued by Mr. Cyrus H. K. Curtis to all the twenty-two hundred workers of the campaign to dine with him at the Benjamin Franklin Hotel on the evening of Friday, December fifth, at which time Mr. Curtis will serve as host. He stated that the purpose of the dinner was to have a reunion of those who helped so splendidly to make the campaign a success, in the hope that the fine spirit and remarkable interest shown in June would be maintained and strengthened with the passage of time. He urged all members of the Institute who had been worker to accept the invitations which had been sent them. He stated also that at this dinner perspective drawings and a large scale model of the new building would be displayed for examination by all who attended.

The Secretary referred to the Christmas Week Lectures on the James Mapes Dodge Foundation and stated that the subject of the lectures for this year will be "The Scientific Work of Benjamin Franklin," a topic of peculiar interest at this time. The lecturer will be Dr. E. E. Free of New York University, an outstanding figure in scientific publicity work of the country. If Dr. Free's lectures are at all comparable with the outlines which have been offered of them, they will prove to be among the best yet delivered before the Institute.

The Secretary further announced concerning progress being made in the affairs of the Institute that the new development had made it desirable to have an additional Vice-President. The appointment of such an officer had been authorized by the amendment of the by-laws. At the meeting of the Board of Managers just held, Mr. W. Chattin Wetherill was elected from the Board of Managers to fill this new office. Mr. Wetherill is a descendant of a founder of the Institute. His forebears were leaders in the development of chemical interests and industries in the early days of Philadelphia. He brings to the work of his new office a warm enthusiasm and high ability.

The President announced that there was no further business and immediately introduced as the speaker of the evening Mr. R. T. Haslam, Manager of the Standard Oil Development Company. Mr. Halsam delivered a most interesting talk

before an audience which filled the lecture hall to overflowing. He gave a brilliant outline of "The Hydrogenation Process in Petroleum Refining."

The meeting was adjourned at nine-forty-four with a rising vote of hearty thanks to Mr. Haslam for his most interesting talk.

HOWARD MCCLENAHAN,
Secretary.

RESOLUTION ADOPTED IN REFERENCE TO THE DEATH OF JAMES T. WALLIS.

The Board of Managers of The Franklin Institute of the State of Pennsylvania wishes to record its sense of great loss in the death of Mr. James T. Wallis, a member of the Board since 1923, and to express the fullest sympathy to the members of Mr. Wallis' family in their bereavement.

As a member of this Board, Mr. Wallis brought to its meetings a comprehensive knowledge of mechanical things, a sympathetic understanding of human relations, and a fine tolerance of differences of opinion. His knowledge and his judgment made him a wise leader in the affairs of the Institute.

The members of this Board had for Mr. Wallis warm liking and high respect, and were grateful for the opportunity of association with him. They have lost a sincere friend whom they esteemed greatly.

The Board directs that this minute be spread upon its records and that a copy of it be transmitted to the family of Mr. Wallis.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 12, 1930.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 12, 1930.

MR. HENRY B. ALLEN *in the Chair.*

The following reports were presented for first reading:

No. 2902: Televox.

No. 2907: Work of Doctor George W. Carver.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 19, 1930.*)

RESIDENT.

MR. ROBERT W. ELLMS, Mechanical Research Engineer, Philadelphia Coke Company, 4501 Richmond Street. For mailing: 3435 North Twenty-third Street, Tioga Manor, Philadelphia, Pa.

MR. FRANK N. KNEAS, Chief Engineer, John T. Windrim, Architect, 1501 Commonwealth Building, Philadelphia, Pa.

MR. J. STOGDELL STOKES, Manufacturer, Summerdale, Philadelphia, Pa.

NON-RESIDENT.

DR. MILDRED ALLEN, Instructor in Physics, Oberlin College. For mailing: 128 Forest Street, Oberlin, Ohio.

MR. L. W. CHUBB, Research Engineer, Director, Westinghouse Research Laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

NECROLOGY.

Dr. Herbert Henry Dow, Midland, Michigan.
Dr. Ellwood Hendrick, New York City.
Mr. A. W. Thompson, Philadelphia. Pa.
Mr. J. T. Wallis, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. ONWARD BATES, 934 John's Road, Augusta, Ga.
MR. ALFRED E. BLAKE, 207 Malvern Apartment, 93 Seward Street, Detroit, Michigan.
MR. ALFRED T. BRATTON, 7823 Fillmore Street, Fox Chase, Philadelphia, Pa.
MR. WILLIAM L. BROWN, 3d, 1142 Broad Street Station Building, Philadelphia, Pa.
MR. CHARLES H. COLVIN, Nine Prospect Park West, Brooklyn, N. Y.
MR. ROBERT CRAIG, 233 Broadway, New York City.
MR. ARTHUR FALKENAU, Stamford Hall, Stamford, Conn.
MR. RALPH E. FLANDERS, Box 476, Springfield, Vt.
MR. F. LYNWOOD GARRISON, 333 South Hicks Street, Philadelphia, Pa.
MR. HARRY A. GOULD, 121 West Tulpehocken Street, Germantown, Phila., Pa.
MR. H. ARTHUR GROSSCUP, 17 North Thirtieth Street, Camden, N. J.
DR. EDWARD C. HAINES, 625 Avondale Avenue, Haddonfield, N. J.
DR. JOHN MCARTHUR HARRIS, JR., 918 Convention Street, Baton Rouge, La.
MR. CHARLES HART, P. O. Box 148, Media, Pa.
MR. NATHANAEL G. HERRESHOFF, P. O. Box 116, Cocoanut Grove, Fla.
MR. MAURITZ C. INDAHL, Panther Road, Rydal, Pa.
MR. MARTIN HILL ITTNER, c/o Colgate-Palmolive-Peet Company, Jersey City, N. J.
MR. ALFRED P. LOHMANN, Sugartown Road, Devon, Pa.
MR. PERCY C. MADEIRA, 260 South Broad Street, Philadelphia, Pa.
MR. SIMON MILLER, Apartment 401, 1520 Spruce Street, Philadelphia, Pa.
MR. JOSEPH W. MYRES, c/o Proctor and Schwartz Electric Co., Seventh Street and Tabor Road, Philadelphia, Pa.
MR. CARROLL B. NICHOLS, 3100 Lewis Tower, Fifteenth and Locust Streets, Philadelphia, Pa.
MR. A. F. SHATTUCK, P. O. Box 796, Indio, California.
MR. JOHN P. B. SINKLER, 1908 Architects' Building, Philadelphia, Pa.
DR. ANCEL ST. JOHN, 505 Fifth Avenue, New York City.
MR. WILLIAM H. THUROW, Falkenhain-Finkenkrug, Augusta-Viktoria-Allee 15, Berlin, Germany.
MR. E. T. TURNER, 150 Scarborough Street, Hartford, Conn.
MR. FRANCIS B. VOGDES, 92 Wayne Avenue, White Plains, N. Y.

LIBRARY NOTES.

RECENT ADDITIONS.

American Concrete Institute. Proceedings. Volume 26. 1930.

American Electrochemical Society. Transactions. Volume 57. 1930.

American Institute of Chemical Engineers. Transactions 1929. Volume 23. 1930.

BRAND, LOUIS. Vectorial Mechanics. 1930.

BROGLIE, LOUIS DE. An Introduction to the Study of Wave Mechanics. Translated from the French by H. T. Flint. 1930.

Chemical Engineering Catalog. Fifteenth annual edition. 1930.

DIEDERICHS, HERMAN, AND WILLIAM C. ANDRAE. Experimental Mechanical Engineering. Volume I. 1930.

DIETERICH, KARL. The Analysis of Resins, Balsams and Gum Resins. With a bibliography. Translated from the German. Second English edition, revised and enlarged, by H. B. Stocks. 1920.

ERRERA, J. Polarisation Diélectrique: Refraction des Radiations depuis les Rayons X jusqu'aux Ondes Hertziennes. 1928.

Forschungsinstitut der čechoslovakischen Zuckerindustrie in Prag. Bericht für das Jahr 1929–1930. Band 33. 1930.

GIBBS, R. W. M. The Adjustment of Errors in Practical Science. 1929.

GOLDSTEIN, E. Canalstrahlen. Ostwald's Klassiker der exakten Wissenschaften. Nr. 231. 1930.

HARRISON, G. CHARTER. Standard Costs: Installation, Operation and Use. 1930.

HARRISON, WARD, O. F. HAAS and KIRK M. REID. Street Lighting Practice. 1930.

HEYL, PAUL R. New Frontiers of Physics. 1930.

JAEGER, F. M. (1) Spatial Arrangements of Atomic Systems and Optical Activity. (2) Methods, Results and Problems of Precise Measurements at High Temperatures. (3) The Constitution and Structure of Ultramarines. 1930.

JOHNSON, CHARLES MORRIS. Rapid Methods for the Chemical Analysis of Special Steels, Steel-Making Alloys, Their Ores, Graphites, and Bearing Metals. Fourth edition. 1930.

JONES, FRANKLIN D., editor. Ignenious Mechanisms for Designers and Inventors. 1930.

LOVELL, ALFRED H. Generating Stations. Economic Elements of Electrical Design. First edition. 1930.

MAERZ, A., and M. REA PAUL. A Dictionary of Color. First edition. 1930.

MARTI, OTHMAR K., and HAROLD WINOGRAD. Mercury Arc Power Rectifiers: Theory and Practice. First edition. 1930.

MILLER, KEMPSTER B. Telephone Theory and Practice: Theory and Elements. 1930.

Mineral Industry: Its Statistics, Technology and Trade During 1929. Volume 38. 1930.

MOSELEY, SYDNEY A., and H. J. BARTON CHAPPLE. Television To-day and To-morrow. No date.

OLIVIER, CHARLES P. COMETS. 1930.

RICHARD, P. J. La Gamme: Introduction a l'Étude de la Musique. 1930.
SHANNON, R. W. Sheet Steel and Tin Plate. 1930.
SIEGEL, G. Die Elektrizitätsgesetzgebung der Kulturländer der Erde. Three volumes. 1930.
SMITHELLS, COLIN J. Impurities in Metals. Second edition, revised. 1930.
SOMMERFELD, ARNOLD. Wave Mechanics. Translated from the German edition by Henry L. Brose. 1930.
SPURR, HENRY V. Wind Bracing: the Importance of Rigidity in High Towers. 1930.
SUTHERLAND, HALE, and HARRY LAKE BOWMAN. An Introduction to Structural Theory and Design. Theory. 1930.
THOMAS, R. E. Stowage: the Properties and Stowage of Cargoes. 1930.
Thomas' Register of American Manufacturers. Twenty-first edition. 1930.
United States Department of Commerce. Commerce Yearbook 1930, Volume I. 1930.
WEBEL, A. A German-English Technical and Scientific Dictionary. 1930.
WIEN, W., and F. HARMS, Editors. Handbuch der Experimentalphysik. Band 25, 3 Teil. 1930.
WOLDMAN, NORMAN E. Physical Metallurgy. Laboratory Manual. 1930.
WOOD, A. B. A Textbook of Sound. 1930.
ZWORYKIN, V. K., and E. D. WILSON. Photocells and their Application. 1930.

BOOK REVIEWS.

MANUEL DE RECEPTION RADIO-ELECTRIQUE, par Pierre David, Ancien eleve de l'Ecole Polytechnique, Docteur es sciences, Ingenieur au Laboratoire National de Radio-Electricite. VII–308 pages, 8vo, paper. Paris, Masson et Cie., Editeurs. 1930. Price 36 francs.

A generally satisfactory characteristic of a handbook is that it be compact, comprehensive and not hopelessly brief. M. David appears to have satisfied that specification in the present volume. The work is intended for readers of varied mathematical attainment, who already have some knowledge of the subject, and to that end only a minimum of the more simple calculations are current in the text, while demonstrations which demand a marked mathematical capacity are appended in small type.

The general plan followed is a consideration, first, of fundamental phenomena and their particular applications. The work commences with the waves to be received, the various types of signals, parasites and beats; then come wave receivers, selectivity and its relation to frequency. Amplification and reaction each receive a lengthy chapter. Detection and the examination of a variety of detectors, and heterodyne, superheterodyne and modulators also are each given a chapter. In a final chapter are collected practical data on the choice and construction of receiving sets with especial reference to the quality of reception. The work is a clear and logical presentation of the application of the principles of radio engineering in convenient form for reference, as well as for systematic study.

L. E. P.

SHEET STEEL AND TIN PLATE. By R. W. Shannon, Associate Member American Institute of Mining and Metallurgical Engineers. 283 pages, 69 illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1930. Price $5.00.

To those uninitiated in the methods of sheet steel and tin plate manufacture, this book will contain many interesting revelations. Perhaps it is not amazing that those of us who are uninformed should believe that for the production of a steel sheet it was only necessary to feed the piece of steel into one end of a machine or set of rolls and the finished product automatically emerged from the other end. Only those directly involved in the manufacture of sheet steel realize how much depends upon the skill of experienced workmen and what great care must be exercised in order to secure uniformity of dimension, correct internal structure, and smoothness of surface.

The author has written this book with the object of acquainting the layman with one particular phase of steel fabrication—that of steel sheets and their plating with zinc, tin and a lead-tin alloy (terne plate). Readers will find themselves amazed over the complexities of the sheet making process which involve numerous stages of heating, rolling, annealing, deoxiding, oxidizing, pickling, plating and finishing. Although impossible to give complete details in a book such as this, the author has dealt very comprehensively with his subject. After giving a brief survey of industrial iron products in general and a statement on the annual production of sheet steel in America, Mr. Shannon begins with a description of the types of steel used and the general methods of transforming this steel into sheets. The details of the process are treated under such headings as—Hot-Rolling and Shearing, Annealing, Pickling, Cold-Rolling, Resquaring, Flattening, Oiling, Protective Coatings, Metallic Coating Processes, Forming and Painting, Preparation for Shipment and Classification. Several Appendices of useful information are added to the book. These include short chapters on the Nature and Effects of Annealing of Sheet Steel, Definition of Terms, Abbreviation for Treatments, Finishes and Quality of Sheet Products and, How to Specify Steel Products. A very useful bibliography also is appended.

T. K. CLEVELAND.

ARTIFICIAL SUNLIGHT. By M. Luckiesh, D.Sc., Director of the Lighting Research Laboratory of the Edison Lamp Works—National Lamp Works, General Electric Company, Nela Park, Cleveland, Ohio. 254 pages, 8 full-page plates, 65 figures, 8vo. New York, D. Van Nostrand Co., Inc., 1930. Price $3.75.

Artificial illumination, until very recently, has been considered only as a means of ameliorating darkness. With the discovery of the physiological functions of the invisible radiations of sunlight, and the knowledge that the natural radiation is often insufficient (resulting in such diseases as rickets), artificial sources, especially of ultraviolet rays, have come into rather wide use. First employed in the hospital, then in the form of units for the home, most of these devices have been designed mainly for their physiological benefit, and no one was expected to use them for general illumination.

According to Dr. Luckiesh, however, we are now on the dawn of a new era in lighting—an era in which lighting engineers will strive to reproduce the health-

giving powers of sunlight as well as its mere illuminating properties. "In the new era of lighting," he says "midday summer sunlight must be simulated sufficiently closely to be safe to use over long periods and with no more precautions than are necessary in exposure to natural sunlight." Thus, there will be no need, for instance, of the goggles now used to protect the eyes when such ultraviolet sources as the bare arc, or the quartz tube mercury arc, are being employed.

As an authority on lighting problems, Dr. Luckiesh is outstanding. His books on other illumination topics include the well-known "Light and Shade and Their Applications," "Color and Its Applications," and "Visual Illusions" as well as several others. "Artificial Sunlight" is written in his usual lucid and interesting style and, in addition, if his prophecies are correct, it may eventually rank as a classic in the literature of illuminating engineering.

After a preliminary discussion of the general problem, the author discusses the sun's radiation in some detail, then the effects of spectral energy of different wave-lengths. Then he considers at length the erythemal basis that he advocates for the standardization of sources of artificial sunlight. The amount of erythema, or "sunburn," is closely associated with other beneficial effects of radiation. Of course, as he points out, for dual-purpose lighting the ultraviolet intensity must be less than that required for the production of erythema, because of the relatively long exposures that one would receive with its use.

Some form of reflector is required for any lighting unit, if it is to be efficient, so a chapter is devoted to the subject of the reflection of ultraviolet light. It appears that aluminum, either polished or oxidized, chromium, bleached cotton and snow are among the best reflectors, as they return 60 per cent. or more of the incident radiation of the short wave-lengths. Nickel, steel and white paper each reflect between 40 and 60 per cent., while silver reflects less than 20 per cent. The next chapter, quite naturally, is devoted to transmitting media, for they also must be used in lighting units. Fused quartz is the best but several kinds of special glass approach rather closely to it when new.

Though ultraviolet radiation has gotten the most attention, sunlight is also rich in the infrared, which also has its physiological function and must be reproduced. Therefore, we find a chapter devoted to it. Then the important topic of permanency of the transmissive powers of quartz and glass is treated. This indicates that quartz is quite permanent in its transparency to the shorter waves, but some of the types of glass soon fall to less than half of their transmission when new. Methods of measuring ultraviolet light are considered, and in the final chapters he describes sources of artificial sunlight and their use. In this part a large share of attention is given the General Electric "Sunlight lamp," which is a product of Dr. Luckiesh's own laboratory. But this is not due to any prejudice on the author's part. Rather is it because of the convenience of this source and the fact that, at the time the book was written, it was the only light of this kind on the market. Within the last few months the Westinghouse Company has introduced a somewhat similar lamp that embodies some novel features.

Concluding, Dr. Luckiesh says:

"Thus, it is seen that artificial sunlight can be more than a safe and unfailing substitute for midday midsummer sunlight during the entire year. It provides this indoors where potent sunlight can seldom be obtained. Here again, artificial

lighting not only successfully challenges the sun and makes the indoor world independent of it, but it is much more practicable. As to cost, it is a very small part of the cost of production or of living. Adequate natural sunlight for health as well as for vision cannot be obtained in most of our indoor world at any cost."

JAMES STOKLEY.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 351. Full Scale Wind Tunnel Tests of a Propeller with the Diameter Changed by Cutting off the Blade Tips, by Donald H. Wood. 25 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price fifteen cents.

Tests were conducted in order to determine how the characteristics of a propeller are affected by cutting off the tips. The diameter of a standard 10-foot metal propeller was changed successively to 9 feet 6 inches, 9 feet 0 inches, 8 feet 6 inches, and 8 feet 0 inches. Each propeller thus formed was tested at four pitch settings in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics using an open cockpit fuselage and a D-12 engine.

A small loss in propulsive efficiency is indicated. Examples are given showing the application of the results to practical problems.

Report No. 352. Large-Scale Aerodynamic Characteristics of Airfoils as Tested in the Variable Density Wind Tunnel, by Eastman N. Jacobs and Raymond F. Anderson. 32 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price twenty cents.

In order to give the large-scale characteristics of a variety of airfoils in a form which will be of maximum value, both for airplane design and for the study of airfoil characteristics, a collection has been made of the results of airfoil tests made at full-scale values of the Reynolds Number in the variable density wind tunnel of the National Advisory Committee for Aeronautics. They have been corrected for tunnel wall interference and are presented not only in the conventional form but also in a form which facilitates the comparison of airfoils and from which corrections may be easily made to any aspect ratio.

An example showing the method of correcting the results to a desired aspect ratio has been given for the convenience of designers. In addition, the data have been analyzed with a view to finding the variation of the aerodynamic characteristics of airfoils with their thickness and camber.

Report No. 354. Aircraft Woods: Their Properties, Selection and Characteristics, by L. J. Markwardt. 34 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price twenty cents.

Wood has been one of the pioneer materials in aircraft construction. Its salient qualities—a high ratio of strength to weight; lightness, affording readily the size of member required to resist twisting and lateral buckling; ease of manufacture; facility of repair without specialized equipment and without highly skilled labor; and adaptability to small-scale production—have always permitted it to serve usefully. Although a lack of uniformity in the quality of wood is perhaps the most important factor now militating against its continued use in present-day quantity production, the existing detailed knowledge of the properties and the

causes of variation in them, determined at the Forest Products Laboratory and submitted to the National Advisory Committee for Aeronautics for publication, makes it possible to select aircraft material with assurance and places design on a reliable basis.

Strength values of various woods for aircraft design for a 15 per cent. moisture condition of material and a 3-second duration of stress are presented, and also a discussion of the various factors affecting the values. The toughness-test method of selecting wood is discussed, and a table of acceptance values for several species is given.

This report presents, further, information on the properties of various other native species of wood compared with spruce, and discusses the characteristics of a considerable number of them from the standpoint of their possible application in aircraft manufacture to supplement the woods that are now most commonly used.

Report No. 355. Comparative Flight Performance with an N. A. C. A. Roots Supercharger and a Turbocentrifugal Supercharger, by Oscar W. Schey and Alfred W. Young. 14 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price ten cents.

As there are now several types of superchargers in service, information on the comparative performance obtained with each type of supercharger would be of value in the selection of a supercharger to meet definite service requirements. As a part of the program to obtain this information, the National Advisory Committee for Aeronautics conducted tests, using a modified DH-4M2 airplane with a turbocentrifugal and with a Roots type supercharger. The rate of climb and the high speed in level flight of the airplane were obtained for each supercharger from sea level to the ceiling. The unsupercharged performance with each supercharger mounted in place was also determined.

The results of these tests show that the ceiling and rate of climb obtained were nearly the same for each supercharger, but that the high speed obtained with the turbocentrifugal was better than that obtained with the Roots. The high-speed performance at 21,000 feet was 122 and 142 miles per hour for the Roots and turbocentrifugal, respectively.

Report No. 358. Temperature Coefficient of the Modulus of Rigidity of Aircraft Instrument Diaphragm and Spring Materials, by W. G. Brombacher and E. R. Melton. 16 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price ten cents.

Experimental data are presented on the variation of the modulus of rigidity in the temperature range -20 to $+50°$ C., of a number of metals which are of possible use for elastic elements for aircraft and other instruments. The method of the torsional pendulum was used to determine the modulus of rigidity and its temperature coefficient for aluminum, duralumin, Monel metal, brass, phosphor bronze, coin silver, nickel silver, three high carbon steels, and three alloy steels. The temperature coefficient m is defined by the relation

$$m = \frac{1}{G_0}\frac{dG}{dT},$$

in which G and G_0 are the moduli of rigidity at the temperatures $T°$ C. and 0° C.

The differential dG/dT was found to be a constant except for two metals. The effect of heat treatment on m was determined for a number of the materials. It was observed that tensile stress affected the values of the modulus by amounts of 1 per cent. or less.

Report No. 360. Pressure Distribution over a Symmetrical Airfoil Section with Trailing Edge Flap, by Eastman N. Jacobs and Robert M. Pinkerton. 19 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price fifteen cents.

Measurements were made in the Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics to determine the distribution of pressure over one section of an R. A. F. 30 (symmetrical) airfoil with trailing edge flaps. In order to study the effect of scale, measurements were made with air densities of approximately 1 and 20 atmospheres.

Isometric diagrams of pressure distribution are given to show the effect of change in incidence, flap displacement, and scale upon the distribution. Plots of normal force coefficient versus angle of attack for different flap displacements are given to show the effect of a displaced flap. Finally, plots are given of both the experimental and theoretical characteristic coefficients versus flap angle, in order to provide a comparison with the theory. It is concluded that for small flap displacements the agreement for the pitching and hinge moments is such that it warrants the use of the theoretical parameters. However, the agreement for the lift is not as good, particularly for the smaller flaps. In an appendix, an example is given of the calculation of the load and moments on an airfoil with hinged flap from these parameters.

ASTRONOMY. By John Charles Duncan, Ph.D., Professor of Astronomy and Director of the Whitin Observatory, Wellesley College. 435 pages, 65 full-page plates, 180 figures, 8vo. New York, Harper and Brothers, 1930. Price $3.75.

About eight years ago it was a matter for regret among astronomers, especially those who were also teachers, that there was no adequate and modern text in the subject. Then a veritable flood of them appeared, each having its good points. Of these, probably the best single volume was Dr. Duncan's "Astronomy," the first edition of which appeared in 1926. The cordial reception given it has now necessitated a second edition, and this has furnished Professor Duncan the opportunity of including the important astronomical discoveries that have been made in the last four years. One of the most recent to be thus included is the discovery, made last spring by astronomers at the Lowell Observatory, Flagstaff, Arizona, of Pluto, the trans-Neptunian planet. While some astronomers were properly skeptical at first, Pluto has now taken its place as a respectable member of the family of major planets, even though it is probably smaller than the earth, not as large as it seemed originally.

Fortunately, this discovery was made before the book was completely printed, so this is the first and, at the time this review is written, the only text-book to contain the name of Pluto with an account of its discovery. There was not, however, time to include the newest orbit computations. These were based on the discovery of earlier photographs of the planet, some made at Mt. Wilson as early as 1919.

They immediately gave a series of observations extending over eleven years, and including a good sized arc of Pluto's orbit. Thus, within a few months of the announcement of the discovery, an orbit was calculated with an accuracy that could not otherwise have been obtained without waiting for another decade.

Another new concept, that has been announced for the first time this year and that Professor Duncan covers, is the theory of Dr. Shapley, of Harvard, that our Galactic System of stars, including the Sun, the Milky Way and all the stars that we see in the night sky, is really a super-galaxy. Dr. Shapley has studied in detail such aggregations, the best example of which is the cluster of several hundred extra-galactic nebulæ (largely spirals) in the constellations of Virgo and Coma Berenices. In order to explain the apparently abnormal size of our Galaxy if it is an ordinary spiral, as Easton suggested, Dr. Shapley proposed that it is actually a condensation of such a swarm of nebulæ.

As recently as last summer, however, new researches have been announced, first by Dr. R. J. Trumpler, of the Lick Observatory, and later by Dr. Piet van de Kamp, of the McCormick Observatory, which indicate that there is a considerable absorption in space of light from distant stars, especially those in the Milky Way. This in turn indicates that the farthest ones in the plane of the Galaxy are really much closer than we thought six months ago. If this is true, then the Galactic System is of a more reasonable size, possibly no greater than a typical spiral. This is one of the most important problems now confronting astronomy, and the next few years should give the answer.

In all respects Professor Duncan's book is up to the high standard set by the first edition. He is especially to be commended for first introducing the student to the stars themselves—to the constellations. It is perfectly true that most phases of modern astronomical research have little or nothing to do with the constellations and that one can be a great astronomer and not be able to recognize the Great Dipper or Orion. But, after all, these star groupings are fundamental, and form the part of astronomy most familiar to the layman. Therefore, it seems pedagogically sound to start a study of astronomy with them. When the Fels Planetarium is opened in The Franklin Institute Museum, we shall be able to introduce many to these familiar figures and in a way never before possible. In the book, Prof. Duncan has used a new series of star maps, showing on eight full page plates about four hundred of the brightest and most familiar stars. These are well printed as white stars on a blue background, the size of the stars being proportional to their magnitude.

In succeeding chapters the usual topics of elementary astronomy are covered. These include the Earth and its motions, the Moon, the Sun, the planets, the law of gravitation, comets and meteors, the evolution of the Solar System, the motions of the stars and their physical properties, star clusters and nebulæ and, in conclusion, a chapter on "Cosmography." In this he discusses such topics as the cosmology of de Sitter, in which, on the basis of Einstein's relativity theory, the universe is considered as finite. The recent work at Mt. Wilson on the extraordinarily high velocities of recession of the distant spiral nebulæ shed some light on this question. The speed record is held at present by a group of nebulæ in the bowl of the Great Dipper. They are apparently so anxious to get away from our part of the universe that they seem to be receding at a speed of 11,500 kilometers

a second. According to the de Sitter hypothesis, these rapid motions are illusory being due actually to the curvature of space.

In the final paragraph of the last chapter, he expresses his views on the possibility of life in other parts of the universe, as follows:

"It is now fairly certain that most of the visible universe, so far as it concerns man or any other form of life of which we know, is sterile. Mars and Venus seem to be the only planets of the Solar System, except the Earth, which could possibly support life. Probably the vast majority of the stars are planetless, for the dynamic encounter by which a planetary system is believed to be engendered can have happened to but few. A quarter or a third of known stars are binary. Of stars which possibly have planets, some are variable and subject their surroundings to intolerable extremes of heat and cold. Even of possibly existing planets few are likely to be in the critical condition of temperature, surface gravity and atmosphere necessary to the delicate thing called life. Yet, if but one star in a million possesses one habitable planet, there are in the Galactic System alone many thousand such abodes, and among them may dwell beings of a far higher order than ourselves."

The book is exceptionally well printed and bound, and no mention of it would be complete without favorable comment on the illustrations, especially the full page plates showing modern photographs of celestial objects. Many of them, including some that are very familiar to the astronomer, have been taken by the author himself through the 100-inch reflector at Mt. Wilson, the world's largest telescope. For a number of years Professor Duncan has spent his summers at this work in the Mt. Wilson Observatory. The reviewer recalls with pleasure a night he spent with him on the Newtonian platform of the 100-inch when some of these were being taken a few years ago.

On the whole, then, though written primarily as a text, this book can confidently be recommended to anyone who wants to learn more about the heavens above him. In addition to being the latest, it is also one of the very best general works on this fascinating science of the stars.

JAMES STOKLEY.

CHEMICAL ENGINEERING CATALOG, 1930. (Fifteenth Annual) Edition. Collected, Condensed and Standardized catalog data of equipment, machinery, laboratory supplies, heavy and fine chemicals and raw materials used in the industries employing chemical processes of manufacture with classified indexes of such equipment and materials, carefully cross-referenced and a technical and scientific books section, cataloging and briefly describing a practically complete list of books in English on chemical and related subjects. 1168 pages, illustrations, quarto. New York, The Chemical Catalog Company, Inc., price ten dollars; to chemical engineers, chemists, heads of chemical engineering departments in universities, technical departments of governments, libraries, etc., three dollars.

As heretofore this volume contains data which will be of great value to all who are actively engaged in any branch of chemistry. Three indexes are supplied: one giving a list of the companies noted in the volume; another the trade names of

many manufactured articles, and a third, an alphabetical list of products. The latter contains under each substance the names of the firms manufacturing it. Again there is a section devoted to technical and scientific books, which contains a list of all modern books in English, dealing with those subjects which would be of interest to the users of the catalog.

The volume is now bound in stiff covers making it more convenient for frequent use.

R.

QUANTITATIVE ORGANIC MICROANALYSES. By Fritz Pregl, D.Sc., Ph.D., Professor of Medicinal Chemistry; Principal of the Medico-Chemical Institute of the University of Graz; Corresponding Member of the Academy of Sciences, Vienna. Second English edition translated from the third revised and enlarged German edition by Ernest Fyleman, B.Sc., Ph.D., F. I. C. Consulting Chemist, Sutton, Surrey. xiv–237 pages, 51 illustrations, 8vo. Philadelphia, P. Blakiston's Son & Co., Inc., 1012 Walnut street, 1930. Price $4.00

Undoubtedly the need today for careful and thoroughly proved methods of quantitative organic microanalysis is as great if not greater than ever before. Biologic and organic chemists are concentrating their attentions more and more upon the smaller elements that play such important rôles in the process of living. Research workers no longer confine themselves to the analyses of a gram of sugar, blood albumen, muscular tissue or fat. They now must learn to work with a few one-thousandths of a gram of an enzyme, vitamin, hormone or toxin.

Manipulators of such minute amounts will find Dr. Pregl's "Quantitative Organic Microanalysis" a very valuable tool. The book contains a wealth of detail so seldom found in present-day texts. Each analytical procedure is carefully described, beginning with its inception then its gradual development into the final improved form. Successful operation is assured only through skilled manipulation and irreproachable technique. To summarize briefly, the book gives detailed directions for the use of the microchemical balance; the determination in minute amounts of organic material the elements carbon, hydrogen, oxygen sulfur, phosphorus, arsenic and the halogens; the micro-electroanalysis for metals; the microanalytical determination of such organic radicals as carboxyl, methoxyl, ethoxyl, methyl, and acetyl; molecular weight determinations, micropolarization by Emil Fischer's method and notes on the purification of small amounts of material.

Ernest Fyleman, the translator, has made the translation as literal as possible in order that the author's exact meaning should be preserved and retained with the greatest degree of accuracy.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

A Study of the Induction Motor, by F. T. Chapman, 289 pages, illustrations, plates, tables, 8vo. New York, John Wiley & Sons, Inc., 1930. Price $5.50.

Alternating Current Bridge Methods, for the measurement of inductance, capacitance, and effective resistance at low and telephonic frequencies, by B. Hague, D.Sc., 391 pages, illustrations, 8vo. New York, Isaac Pitman & Sons, 1930. Price $4.50.

Chemical Engineering Catalog, Collected, condensed and standardized catalog data of equipment, machinery, laboratory supplies, heavy and fine chemicals and raw materials. 1168 pages, illustrations, quarto. New York, The Chemical Catalog Company, Inc., 1930. Price $10.00, to chemists $3.00.

Astronomy, by John Charles Duncan, 435 pages, tables, illustrations, plates, 8vo. New York, Harper & Brothers, 1930. Price $3.75.

U. S. Department of Commerce, National Bureau of Standards, Miscellaneous publication No. 111, Standard Time Zones of the United States and Adjacent Parts of Canada and Mexico as of April 1, 1930. 20 x 30 inches. Washington, Superintendent of Documents. Price ten cents.

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